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Suspended Sediment from Forest Road Construction

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David D. Wooldridge, and Arthur G. Larson.

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Concentrations and total quantities of suspended sediment in portions of Fly Creek, an undisturbed tributary of the Clearwater River in western Washington, were studied during the construction of 1.4 miles of unpaved forest road in the watershed. Fly Creek is a Class A, Excellent, stream with a watershed of 649 acres. Approximately 90% of the 140 to 200 inches of annual precipitation becomes streamflow. The road was constructed in accordance with the Best Management Practices defined by the Washington State Forest Practices Rules and Regulations.

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SUSPENDED SEDIMENT FROM FOREST ROAD CONSTRUCTION

State of Washington

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16. Abstract
Concentrations and total quantities of suspended sediment in portions of Fly Creek, an undisturbed tributary of the Clearwater River in western Washington, were studied during the construction of 1.4 miles of unpaved forest road in the watershed. Fly Creek is a Class A, Excellent, stream with a watershed of 649 acres. Approximately 90% of the 140 to 200 inches of annual precipitation becomes streamflow. The road was constructed in accordance with the Best Management Practices defined by the Washington State Forest Practices Rules and Regulations. Sediment concentrations were determined from water samples taken with ISCO automatic samplers that withdraw 500 ml of water at selected intervals. Only visually turbid samples were analyzed and suspended sediment was measured in mg/l. In the laboratory, a Hach model 2100A turbidometer was used to determine the turbidity. Results show that suspended sediment increased both during and after road construction and that sediment concentrations from the construction were related to the proximity of the construction to the stream and the occurrence of rainfall. Sediment increases were small during construction or log hauling during periods without rainfall. Sediment increases were not dependent on work hours or stream discharge. Sediment increases generally occurred on days after construction or hauling was stopped due to rain. A major impact of the road construction was the rapidness with which rainfall causes the suspended sediment increases. (Seigler-IPA)

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SUSPENDED SEDIMENT FROM FOREST ROAD CONSTRUCTION

Principal Investigator: David D. Wooldridge

Co-Investigator: Arthur G. Larson

College of Forest Resources
University of Washington
Seattle, Washington 98195

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ABSTRACT

Suspended sediment in Fly Creek, a tributary of the Clearwater River on the Olympic peninsula, increased during and after phase of construction of 2.5 miles of unpaved forest road. Construction practices conformed to the Washington State Forest Practices Rules and Regulations, considered at present Best Management Practices. Suspended sediment concentrations from road construction were related to the proximity of activities to streams and the occurrence of rainfall.

Except for activities within the stream channel, suspended sediment increases were small during construction in periods without rainfall. Rain was required before construction or log hauling significantly increased suspended sediment transport. Increases in suspended sediment concentrations generally coincided with rates of rainfall, independent of work hours or stream discharge. Although construction and log hauling made the sediment available, rain was required for transport to the stream. Usually, increased sediment concentrations in streams occurred days after construction or hauling terminated following rain. The rapidity with which rainfall caused increases in suspended sediment transport appears to be one of the major impacts of road construction.

Keywords: Suspended sediment, road construction, BMPs, Forest Practices

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SUSPENDED SEDIMENT FROM FOREST ROAD CONSTRUCTION, FLY CREEK, CLEARWATER RIVER BASIN WESTERN OLYMPICS, WASHINGTON

by

David D. Wooldridge

and

Arthur G. Larson

INTRODUCTION

Impacts of forest harvest operations, including forest road construction, are a focal point of application of portions of the Washington State Forest Practices Act and the Rules and Regulations developed by requirements of the State Act. Federal regulations require states to formulate a water quality management plan which includes both point source and non-point source pollution considerations. Within the point source concept, the chemical and physical properties of discharge water are known, and requirements can be set for both quantity and chemical composition of discharge water through a permit system.

Non-point sources of pollution, however, are more complex. Pollutants introduced through man's activities in forest road construction or silviculturally related management cannot be distinguished from naturally occurring pollutant materials generated by rainfall-runoff phenomena. Concentrations of naturally occurring pollutant materials, in particular suspended sediment, vary widely in tributaries of a major river system and also are highly variable over time within any given tributary. In lieu of establishing pollutant concentration limits for maximum or

permissible amounts, the non-point source pollution concept embraces a relationship between use of a Best Management Practice (BMP) as an effort to protect forest water quality.

The Best Management Practice concept incorporates the relationship of technology of the forest practices, and includes economic considerations in terms of feasibility and the practicality of application of practices. BMPs, as formulated in the Rules and Regualtions, become a substitute for in-stream water quality standards for non-point source discharge of pollutant materials from forest lands. Practices and standards are subject to revision as necessary to achieve the 1983 pollution control goal of providing for the protection and propagation of fishlife and for recreation in and on the water, wherever attainable.

The following report briefly reviews appropriate literature and presents results of a study on sources of suspended sediment from newly constructed forest roads in the western Olympic Mountains. Forest road construction practices conformed to the Washington State Forest Practices Rules and Regulations and may be considered forest road construction under conditions of BMPs. Specifically, the objectives of this research were:

1. Identify concentrations of suspended sediment and quantities transported from phases of forest road construction due to:
   A. Forest road construction and hauling right-of-way logs, and
   B. Rain induced sediment from exposed mineral soil following construction.
2. Identify magnitude of departure and duration of water quality not in conformance with State standards.

SEDIMENT FROM FOREST ROADS

Sediment generally is considered the most significant pollutant in forest streams from forest roads (Brown 1973; EPA 1973; Brown and Krygier 1971; Krygier and Hall 1971). Construction, use and maintenance of forest roads are primary sources of accelerated sediment transport from silvicultural practices (Swanston and Dyrness 1973; Brown and Krygier 1971; Fredriksen 1970). A report on Forest Management in the Bull Run watershed near Portland, Oregon indicates, on the basis of regional statistics, 70 percent of sediment increases from silviculture in forest streams resulted from road construction, rather than type of logging (Frewing Committee Report 1973).

Sources of sediment from road may be divided into two categories: surface erosion and mass failures. Surface erosion of newly exposed soil on cut banks, fills, the road surface, and ditches occurs with first rains. The amount of surface erosion from roads is proportionate to road density. Sediment transported from log hauling and maintenance also is termed surface soil erosion. However, actual construction practices and fall rains prior to road use are the most critical sources. Sediment from both hauling and maintenance was significantly less. Fredriksen (1970), reporting on 1.65 miles of road constructed in a steep 250-acre watershed in the Oregon Cascades, found fall storms immediately after construction caused the stream to carry 250 times (1850 mg/l) more sediment than a nearby undisturbed watershed. A similar study in the Coast Range of Oregon reported surface erosion rates, during the first year following road construction, double that expected without roads (Brown and Krygier 1971, D. D. Harris 1977).

Road use by trucks hauling logs increases suspended sediment concentrations in forest streams (Wooldridge 1979) during light to moderate rain. Extended periods of light to moderate rainfall produced

maximum increases (15 to 20 mg/l) during the work day in suspended sediment concentrations of adjacent streams receiving surface runoff from haul roads. Suspended sediment concentrations remained near background levels during rainless periods, or even with moderate to intense rain but no truck traffic. Wald (1975) reported ditchline suspended sediment was 13 times greater on forest roads with heavy truck traffic than on an unused road. Road maintenance has received little study. Wald (1975) reported road grading immediately increased ditchline suspended sediment 3.6 times during rain.

A variety of processes and chemicals aids in reducing road maintenance. Little is known of the effects of dust and ice control, surface hardeners or paving on stream water quality. A study in the Cascade Mountains of Washington found no residual in the adjacent stream (Wooldridge 1979) after two summer applications of sulfite liquor waste for dust control.

Mass failures related to forest roads may be an important source of sediment in steep terrain or unstable soils. Failures may be caused by sidecasting, addition of fill, inadequate or poorly designed drainage, and over-steepened back slopes (Burroughs et al. 1973, Larse 1971). Road construction in steep mountainous areas requires increased cut and fill slope gradients, with a concomitant increase in mass failure potential. Small additions of sediment from sources of surface erosion occur with rain over time, while mass failures add large quantities of soil, rock, and organic debris quickly to streams during intense rain or rain on snow.

Fredriksen (1970) reported that periodic mass failures associated with roads increased annual sediment losses by 100 times that observed from an undisturbed watershed. Dyrness (1967) found failures associated with road fills, backslope, and road drainage were most numerous during a period of intense landsliding in the winter of 1964-65 in the Cascades of Oregon.

STUDY METHODS

Cooperatively with the Department of Natural Resources (DNR), State of Washington, an area was selected in which a routine forest road was constructed to develop a timber sale. Portions of Fly Creek watershed, a small undisturbed tributary of the Clearwater River on the western Olympic peninsula of Washington, were scheduled for timber harvest (Figure 1). Construction of about 2.5 miles of forest road was required to connect an existing ridgeline road with the Clearwater River mainline. Approximately 1.4 miles of new road would be in the Fly Creek drainage (Figure 2). Construction required two bridges--a concrete span crossing the Clearwater River and a cedar log stringer crossing Fly Creek. Road locations, bridges, and water sampling sites are shown in Figure 2. The study identified increases in concentrations of suspended sediment and total quantities (pounds or tons) of sediment transported during phases of road construction.

THE FLY CREEK STUDY SITE

The Clearwater River is a Class A, Excellent, by Water Quality Standards (WAC, 173-201) with the following criteria applying: "Turbidity shall not exceed 5 NTUs over background turbidity when the background turbidity is 50 NTU or less or has more than a 10% increase in turbidity, when background turbidity is more than 50 NTU." The Clearwater River is also a Type I water Forest Practices Rules[(WAC, 222-16-030)] in the study area, indicating it is a "Shoreline of the State" (mean annual flow greater than 20 cfs). Fly Creek is a Class A or AA stream in the Water Quality Standards and a Type III stream, as it is moderately important for fish spawning and rearing.

The Fly Creek watershed has an area of 649 acres with a northern aspect. The Clearwater River flows primarily west with about 7000 acres

Figure 1. Fly Creek, a small tributary of the Clearwater River had several miles of forest road constructed in the summers of 1976 and 1977.

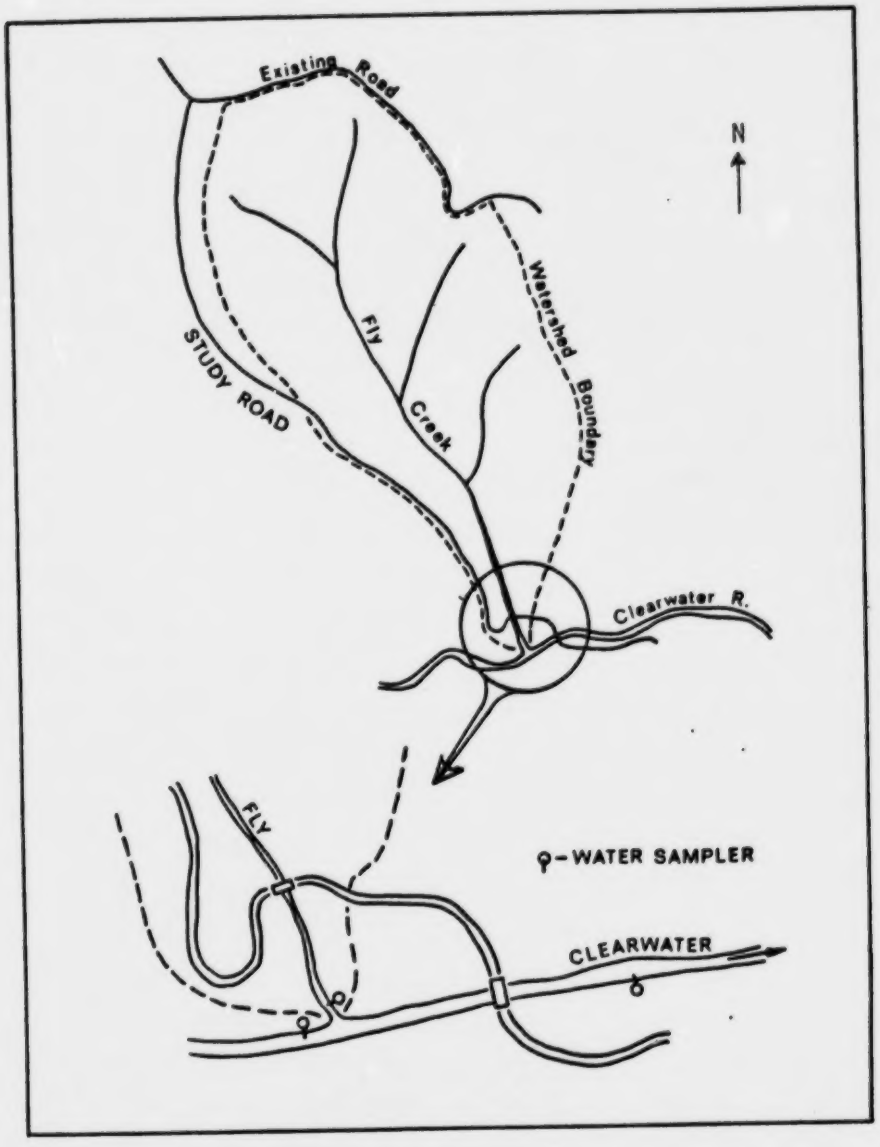

Figure 2. The locations of automatic water samplers are shown in the inset on the lower portion of the page. Discharge of the Clearwater and Fly Creek was also estimated at the sampling stations.

of watershed area upstream of Fly Creek. Annual precipitation ranges between 140 and 200 inches with about 90 percent of precipitation transformed to streamflow. Precipitation occurs primarily as rain with 75 percent of the annual total falling from November through March. Snow, persisting during winter months on ridges (above 200 feet in elevation), contributes only a small percentage to total runoff. Old-growth western hemlock (*Tsuga heterophylla* [Raf.] Sarg.), Pacific silver fir (*Abies amabilis* [Dougl.] Forbes) and western red cedar (*Thuja plicata* Donn) are the major tree spcies. Soils are shallow, underlain by a deeply weathered bedrock of fractured sedimentary sandstone (graywacke).

FOREST ROAD STANDARDS

Road construction adhered to DNR "Forest Management Road" standards. Maximum road grade allowed was 18% favorable (downhill, truck loaded) and 12% adverse (uphill, loaded), with a 60-ft. minimum radius on curves. The right-of-way was cleared of timber for 10 ft. beyond the cut or fill slope on both sides of the road, and stumps removed within two feet. The road was surfaced to a width of at least 12 ft. over a 16-ft. subgrade, and a 3-ft. wide by 1 ft. deep subgrade ditch constructed on all sidehill sections and on both sides through cut sections. Surfacing was crushed rock supported by at least 12 in. of pit-run ballast. Cross culverts (relief) were installed as necessary to carry runoff expected as ditch flow. Culverts were angled at 30^{0} to the road centerline on grades in excess of 3%, and inlets provided with headwalls to direct water into the culvert. Culvert outlets were carried beyond the toe of the road fill and provided with flumes and energy dissipators when terminating an erodible soil. Intervisible turnouts of 50 ft. in length were placed at intervals no greater than every 1000 ft. The roadway was widened 12 ft. at turnouts and 50 ft. of transition provided on either end (total turnout length is 150 ft.).

ROAD CONSTRUCTION

The Fly Creek road branches from the main Clearwater road on the north side of the Clearwater River. It crossed the river and entered the Fly Creek drainage, crossing Fly Creek with a cedar log stringer bridge (Figure 2). Monitoring of road construction activities (9/8/76) included falling of right-of-way ROW) timber, and yarding and decking ROW logs through 10/27/76 when construction was halted for the winter. Approximately 30 stations (3000 ft.) were felled, yarded, and a pioneer grade constructed. About 75 truck loads of ROW timber were removed from 11/8/76 to 11/23/76. Removal of the ROW timber terminated the first year's road construction activities in Fly Creek watershed, and the road was unused from 11/24/76 to 6/27/77. A preformed concrete span bridge was constructed across the Clearwater River during the winter 1976-77.

Road construction was reactivated on 6/28/77; however, rather than continue from where construction was halted the preceding year, the contractor initiated downhill construction from the ridge road. This development complicated monitoring or specific construction activities. Also, the first 6000 ft. of downhill construction were outside the Fly Creek basin (Figure 2). The two road segments were connected on 9/19/77.

Final grading of the road, surfacing, and culvert installations continued until 10/7/77, for all practical purposes completing construction. Remaining ROW logs (approximately 405 truck loads) were hauled across the Clearwater River between 10/12/77 and late January 1978.

From 2/1/78 to 5/4/78, during the second year, there was no road use or construction. Road use for timber hauling of harvest units began on 5/5/78, terminating the road construction study.

FIELD SAMPLING

Suspended sediment concentrations of Fly Creek were determined from water samples obtained by ISCO automatic samplers. ISCO samplers automatically withdraw a 500 ml volume of water at selected intervals.

Sampling intervals varied between 30 minutes and 4 hours, depending upon the road construction activity monitored.

Water samples were visually inspected in the field and discarded when not turbid. Discarded samples were recorded as less than 1 mg/l or 1 NTU and identified by time and conditions when streams were clear or turbid. Turbid samples were returned to the lab and analyzed for both turbidity in NTUs and suspended sediment in milligrams per liter (mg/l).

Laboratory and analytical procedures used in this study are accepted forest hydrology research methods. Determination of suspended sediment concentrations followed modified procedures of Guy (1969), establishing quantities of suspended sediment in water samples through physical filtration of the samples and oven drying of sediment to a constant weight at 105°C. Volumes of water samples were measured and results reported as mg/l. Precision of the analytical methods was limited to +1 mg/l. Therefore, suspended sediment concentrations had to exceed 2 mg/l to be significant. Since 500 ml samples were collected, resulting overall accuracy for any determination was $\pm$2 mg/l. Suspended sediment concentrations less than 1 or 2 mg/l were considered at background level.

Turbidity in NTUs was determined on a Hach model 2100A turbidometer by Standard Procedures described by the manufacturer. Calculating total quantities of sediment transported (in pounds or tons of sediment) and relating sediment to rain required a measure of precipitation and an estimation of stream discharge. Streamflow of Fly Creek was estimated using a correlation technique of stage-discharge relations. Staff gages were installed and discharge measured at sampling sites on both the Clearwater River and Fly Creek. Staff readings of stage were correlated with respective stages of the nearby Solleks River, equipped with a Fischer-Porter water level recorder. Ongoing hydrology research in the Clearwater River basin maintains several gaging stations, such as the Solleks River where Fischer-Porter water level recorders operate continuously to record total stream discharge. Correlation of stream stage

between study streams and the Solleks River gaging station allowed continuous prediction of discharge of study streams. Both the Clearwater River and Fly Creek were individually field rated for discharge in cubic feet per second (cfs) as a function of stage (ft) using a velocity current meter. With the aid of computer, continuous records of discharge of study streams were compiled.

Precipitation was recorded by a standard 8-inch tipping bucket raingage and long-term recorder in a clearcut area near the mouth of Fly Creek. Data collected from this single raingage, although representative of lower elevation rainfall rates and timing, were not necessarily representative of total quantities falling at higher elevations in the Fly Creek watershed.

SUSPENDED SEDIMENT FROM FOREST ROAD CONSTRUCTION

General correlations of suspended sediment transport processes and rain have been recognized in the Northwest by limiting forest road construction to rainless periods in drier spring, summer and early fall months. Analyses of results of this study are divided into periods of construction with and without rain. Suspended sediment transport also varied with rain coincident during working hours of the day or rain during periods of construction, but not necessarily during the 8-hr. work day.

The detailed results of the study are contained in Appendix I as a diary of all activities in three sections: construction, right-of-way timber hauling, and periods of inactivity by the first and second years of seasonal construction in 1976 and 1977.

GENERAL RAINFALL PATTERNS

Precipitation, mainly rain, during 1976-77 fall and winter was only 62% of average (based on 1973 to 1976 average precipitation for a nearby recording station at Clearwater Camp). Road construction could not have been initiated under more ideal conditions. Only 2.7 inches (in.) of rain were recorded during the first construction season (9/8/76 to 10/27/76), less than 20% of normal (approximately 13 in.). Likewise, precipitation during log hauling (November 1976) was only 31% of normal. Precipitation was also 40% below normal during the first winter's inactive period (December 1976 to March 1977).

Total annual precipitation for 1977-78 was about normal. However, summer rain during the second construction season (16.5 in.) was 20% greater than normal (13.5 in. based on 1973 to 1976 records). A high percentage of this rain (7.4 in. or 47%) occurred in September 1977. Monthly precipitation during the remainder of the study was about normal.

Rainfall by sediment sample interval or days during periods of construction is listed in Appendix I. Certain of these rain intensity data also have been summarized in the figures relating sediment transport to discharge.

The effects of road construction activities on suspended sediment transport are grouped in relation of the proximity of the activity to the streams, work and non-work periods, the occurrence of rain, truck traffic, and inactive periods of winter shutdown.

SUSPENDED SEDIMENT WITHOUT RAIN

Suspended sediment was transported during rainless periods only by construction activities in or very close to flowing water in stream channels, or by an activity such as blasting rock or stumps which cause airborne transport of soils to streams. Suspended sediment increases were small and of short duration during phases of road construction without rain. Figure 3 shows short duration sediment increases (21 mg/l, 11 NTUs) from blasting of a rock outcrop a few hundred feet from Fly Creek. Fly Creek sediment concentrations averaged over 10 mg/l (4 NTUs) for over 4 hours (Figure 3).

The road construction contractor chose to construct a temporary bridge over the Clearwater River for equipment access for road construction up Fly Creek in the first construction season. Spreading and grading of the surfacing rock and additional truck traffic over the temporary log stringer bridge resulted in two hours of increased turbidity (89 NTUs). Suspended sediment concentrations in the Clearwater River peaked at 140 mg/l (Figure 4), with an estimated 700 lbs. of suspended sediment transported during the 2-hr. surfacing and grading operations.

The permanent, precast concrete span bridge was constructed over the Clearwater River during the first winter. Equipment was moved in on 12/9/76 with excavation and construction of footings initiated during the week of 12/16/76, and concrete poured during the winter, weather permitting.

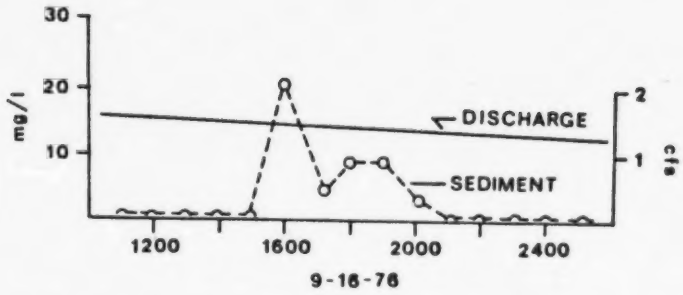

Figure 3. Short duration increase in the suspended sediment concentration of Fly Creek due to road cut rock blasting. The Clearwater River remained clear during this no-rainfall period.

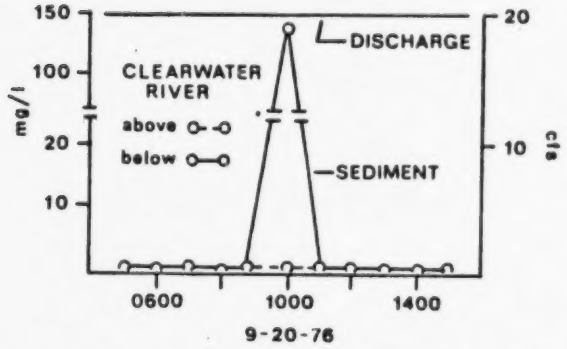

Figure 4. Increase in Clearwater River suspended sediment concentration resulting from earth surfacing of temporary log stringer bridge.

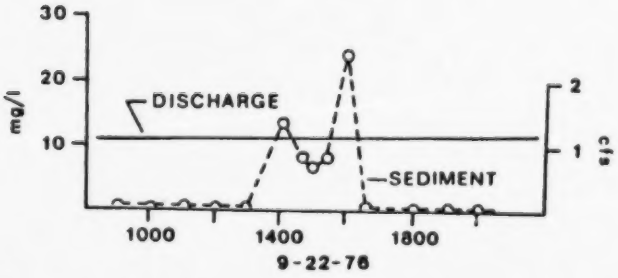

Figure 5. Short duration increase in the concentration of Fly Creek suspended sediment due to streamside excavation for log stringer bridge--raining lightly.

Freezing weather prevented operation of the ISCO samplers during initial excavation and construction of footings; however, visual monitoring did not detect suspended sediment from these activities. Footings were excavated 8 to 10 ft. deep in gravel of the channel but outside the live stream. Water seeping into the bottom of footing excavation pits was pumped into a vegetated area away from the river. Limited rainfall resulted in low discharge of the Clearwater River during the early winter (1976).

No suspended sediment was detected in the Clearwater River during installation of precast concrete girders and bridge surfacing in April and May, 1977. The second bridge constructed provided access across Fly Creek. Suspended sediment concentrations increased to 51 mg/l in Fly Creek during bridge footing excavation and related to bridge construction processes (Figures 5 and 6). The maximum suspended sediment concentration of 267 mg/l on 9/27/76 occurred from sidecast as the eastern approach to the bridge was pioneered. Increases in suspended sediment concentrations occurring during working hours declined to background as work ceased. About 260 lbs. of sediment were transported by Fly Creek from footing excavation and grading in bridge construction. An unknown quantity of sediment was made available for future transport during rain and by high water with increased streamflow.

Suspended sediment from a culvert installation during the second year of construction was the only activity in which sediment source could be separated from the aggregate sediment contributions of preceding construction. On 9/29/77, a culvert was installed in a tributary which joins Fly Creek approximately one-half mile upstream from the sample station. Sediment concentrations in the tributary were not monitored; however, downstream suspended sediment in Fly Creek exceeded 70 mg/l (Figure 7). Sediment concentrations declined to 10-20 mg/l after work was completed and to near background within 24 hours. Sediment transported in Fly Creek due to culvert installation in a tributary was approximately 500 lbs.

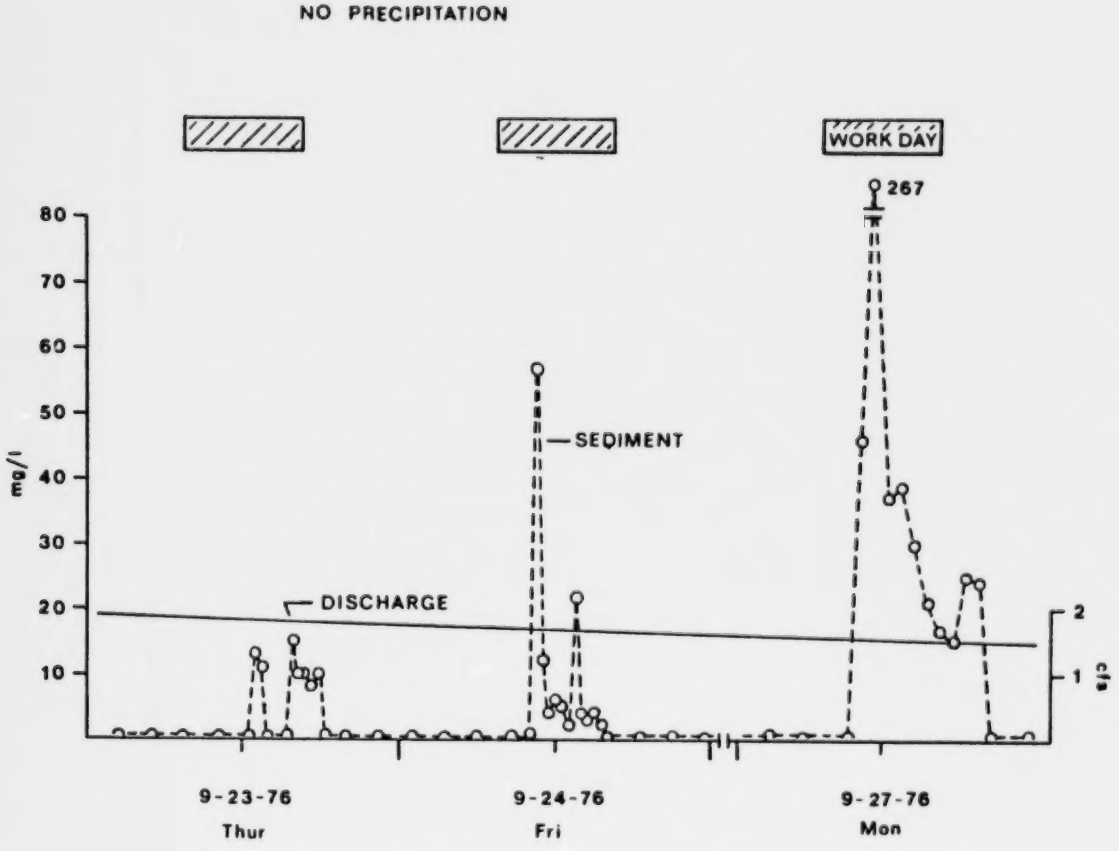

Figure 6. Increases in Fly Creek suspended sediment concentrations resulting from bridge construction. High sediment concentrations on 9/27/76 are due to sidecast material reaching stream.

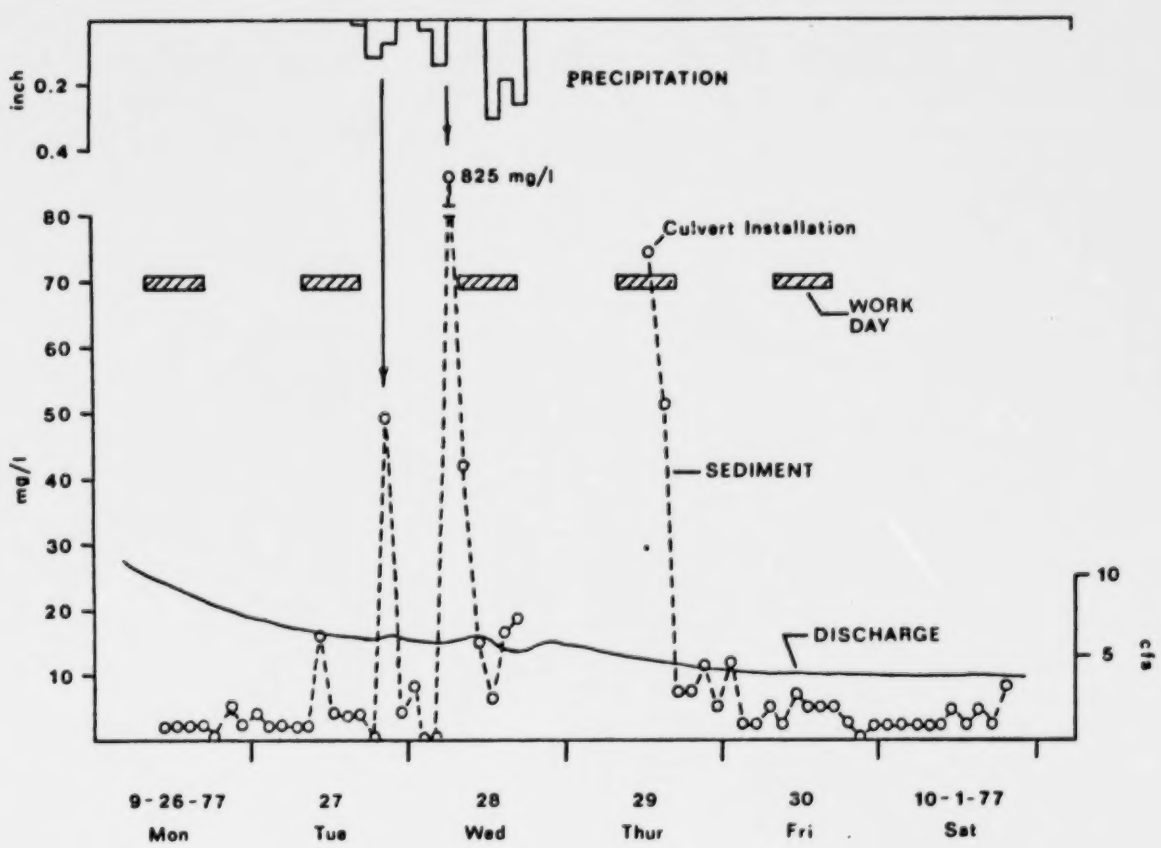

Figure 7. Increases in Fly Creek suspended sediment concentrations resulting from rainfall interacting with newly constructed road. Sediment pulses are not related to any significant increase in stream discharge. High concentrations on 9-29-77 are due to culvert installations on a small tributary stream.

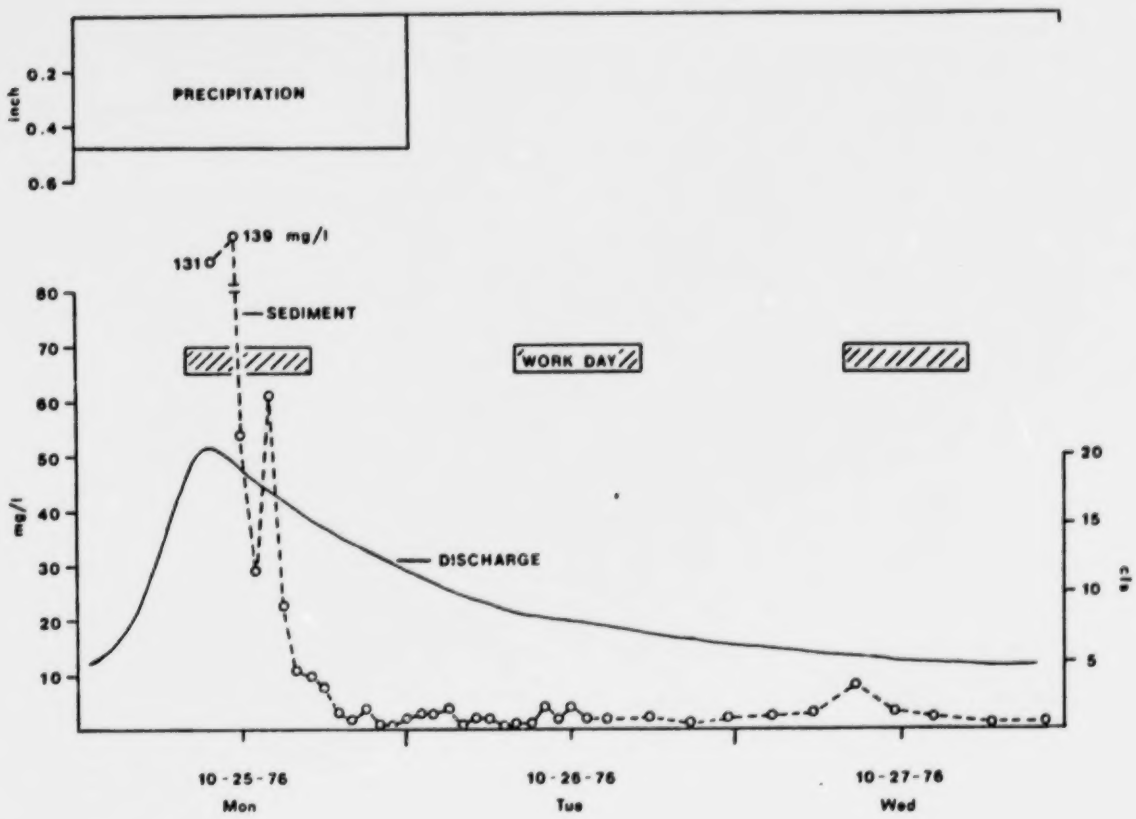

Figure 8. Increases in Fly Creek suspended sediment concentrations resulting from rainfall interacting with hauling of surfacing rock on newly constructed road.

SUSPENDED SEDIMENT WITH RAIN

Rain was required for the effects of construction removed from streams to induce concentrations of sediment transport to Fly Creek. Rain on 10/25/76, combined with road surfacing and gravel hauling during the work day, increased Fly Creek suspended sediment concentration to 139 mg/l (Figure 8). Concentrations reduced to background and remained near background during the next two rainless days, even though similar road construction activities continued.

Suspended sediment in Fly Creek seldom increased during the 8-hour work day without rain. Suspended sediment concentrations generally increased with rain during working hours, non-working or weekends. An increase in suspended sediment occurred in Fly Creek early on 8/24/77 with increased rainfall rates during days of no active work, though construction was in progress (Figure 9). Rain on newly exposed soils and water flow in the road drainage network flushed rapidly sources of available sediment. Fly Creek sediment concentrations declined to background and remained low (8/25 & 26, Fig. 9), even as discharge rates increased.

A similar sediment transport pattern during periods of construction shutdown and intense rains (Figure 10) showed greatest suspended sediment concentrations (165 to 272 mg/l) coincided with peak rainfall intensities. The Fly Creek suspended sediment concentration (78 mg/l), occurring during work with rain (Friday, 9/23/77), was equalled (79 mg/l) with rain only (no construction activity) on Saturday. In Figures 7 and 11, increases in suspended sediment concentrations again coincided with rain, independent of work hours or stream discharge. Similar to Figure 10, peak suspended sediment concentrations occurred with rain prior to peak stream discharge (Figure 11) and during stable or declining discharge (Figure 7). The concentration of 825 mg/l of sediment sampled on 9/28/77 (Figure 7) was probably the result of a rain-induced sidecast failure near the Fly Creek bridge.

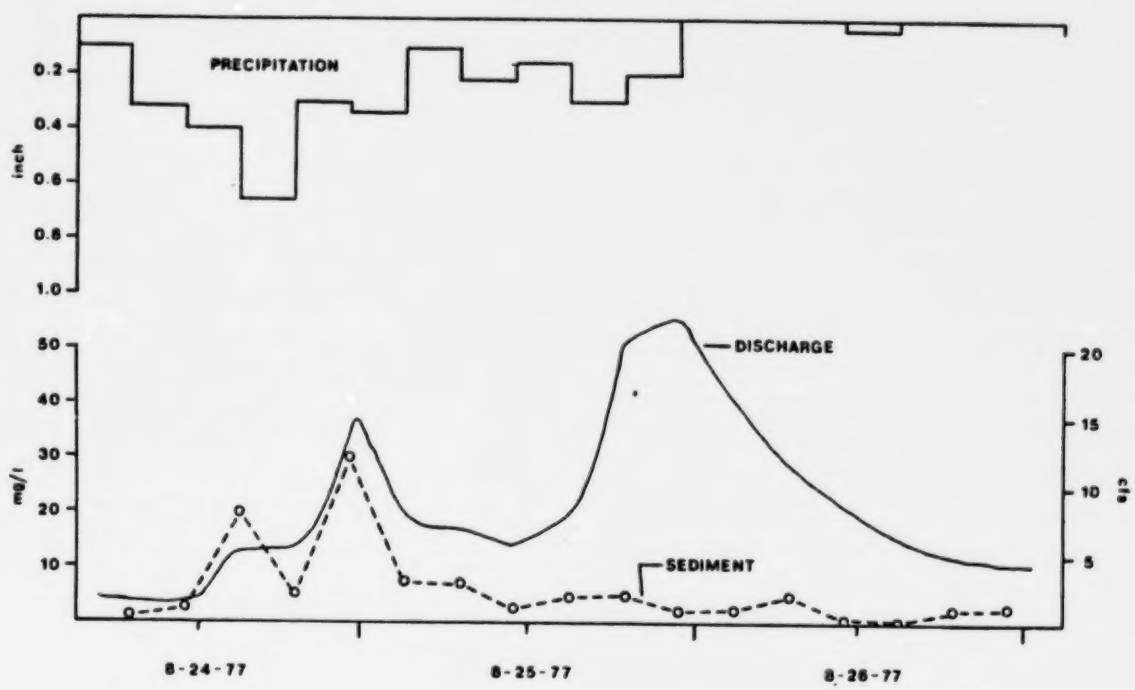

Figure 9. Increases in Fly Creek suspended sediment concentrations following rainfall. Although road construction was still in progress, no active work was performed during this period.

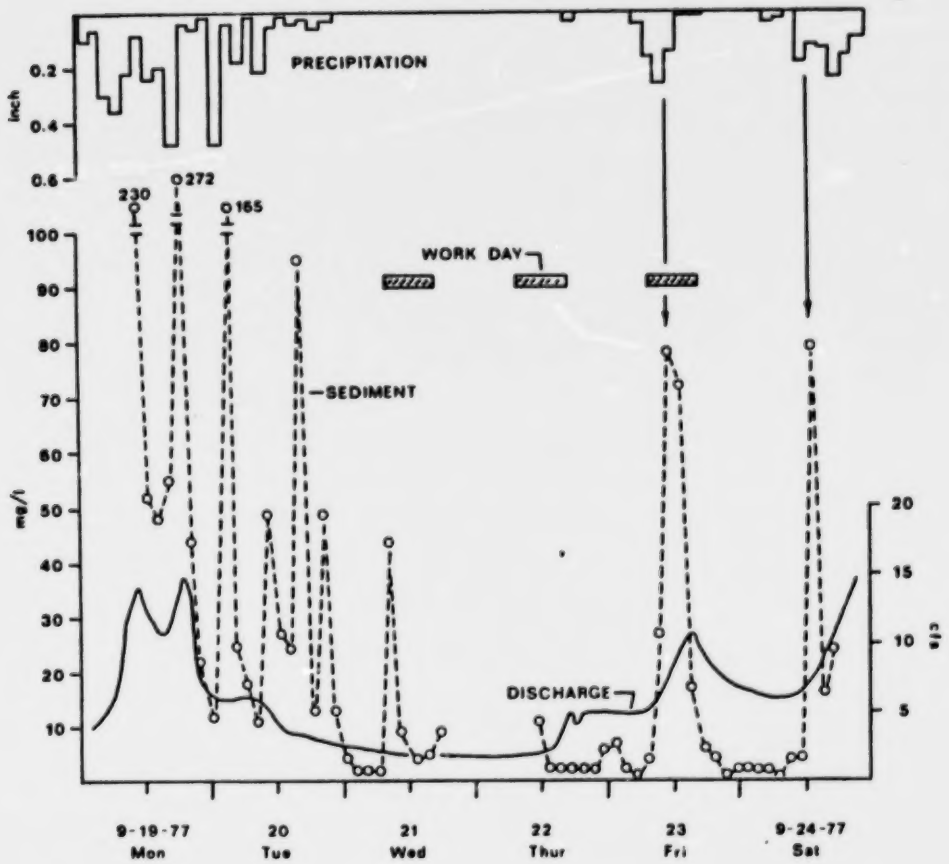

Figure 10. Increases in Fly Creek suspended sediment concentrations resulting from rainfall interacting with newly constructed road. No active work was performed during the maximum rainfall period of 9/19 to 9/20/77.

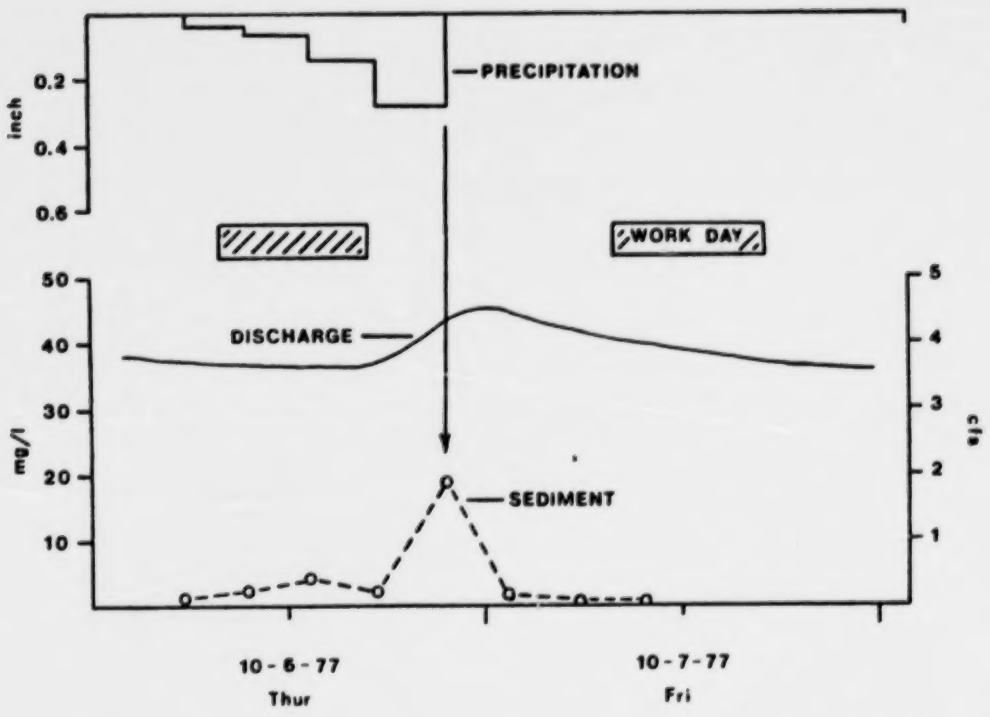

Figure 11. Short duration increase in Fly Creek suspended sediment concentration resulting from rainfall. A partial source of the sediment was drainage from an end haul waste area.

SUSPENDED SEDIMENT AND ROAD USE

Use of newly constructed roads, either with or without ballast and surfacing, frequently induced sediment transport in Fly Creek, particularly during rains. Figure 12 shows substantial increased sediment transport (10/28) caused by a combination of intense rain and road use. Sediment concentration declined to near background overnight. Rain continued on Saturday with little increase in sediment transport; however, intense rain in the early morning of 10/30 (a Sunday) induced sediment concentration of 67 mg/l with a discharge of 245 cfs. This storm was intense and prolonged (7.4 in. of rain), resulting in one of the greatest discharge rates in Fly Creek of the study. Fly Creek transported 13.4 tons of sediment, of which over 9 tons were transported on Sunday, 10/30. Sources of sediment transported on 10/30 were not identified, but were probably from numerous cut slope and sidecast failures as well as high water in channels.

Reduced rain on Monday resulted in rapid reduction in streamflow rates and little or no sediment transport on the work day of 10/31. Road use by hauling of right-of-way logs or gravel trucks hauling rock or surfacing will induce sediment transport during periods of rain (Figure 8).

SUSPENDED SEDIMENT DURING PERIODS OF NO ACTIVITY

Suspended sediment concentrations and transport frequently increased with intense rain during the non-work, winter months. Initial fall and winter rains flushed the available supply of sediment, so that equally intense ensuing rains will not produce equal quantities of sediment transport, a process shown in Figure 13 and Table 1. A rainstorm of 80 hours' duration produced over 8.5 in. of total rainfall between 3/5 and 3/9/77. Short periods of intense rain caused small increases in suspended sediment concentration on 3/5, 6 and 7 as discharge rate increased. The sustained rate of rainfall rapidly increased discharge (77 cfs) in Fly

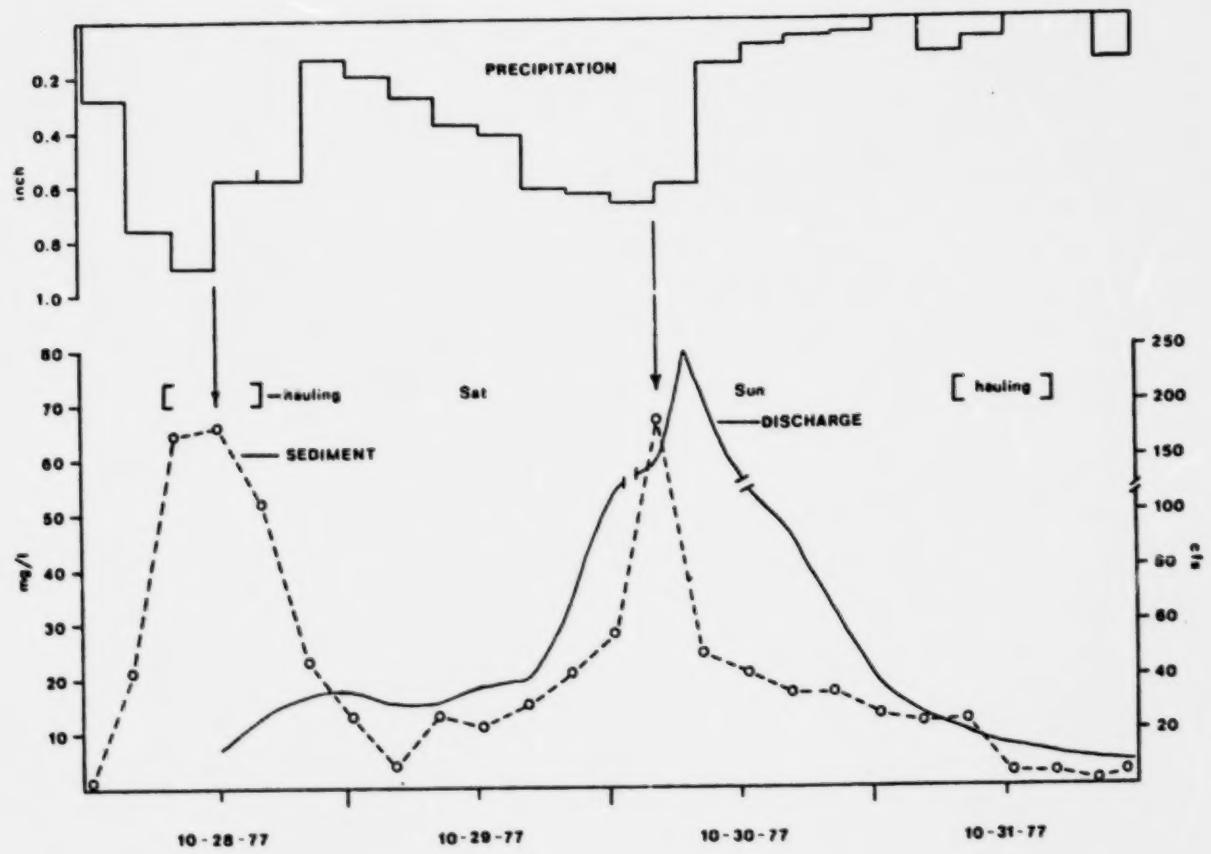

Figure 12. Increases in Fly Creek suspended sediment concentrations resulting from precipitation interacting with truck hauling on 10-28-77 and a major fall storm on 10-30-77.

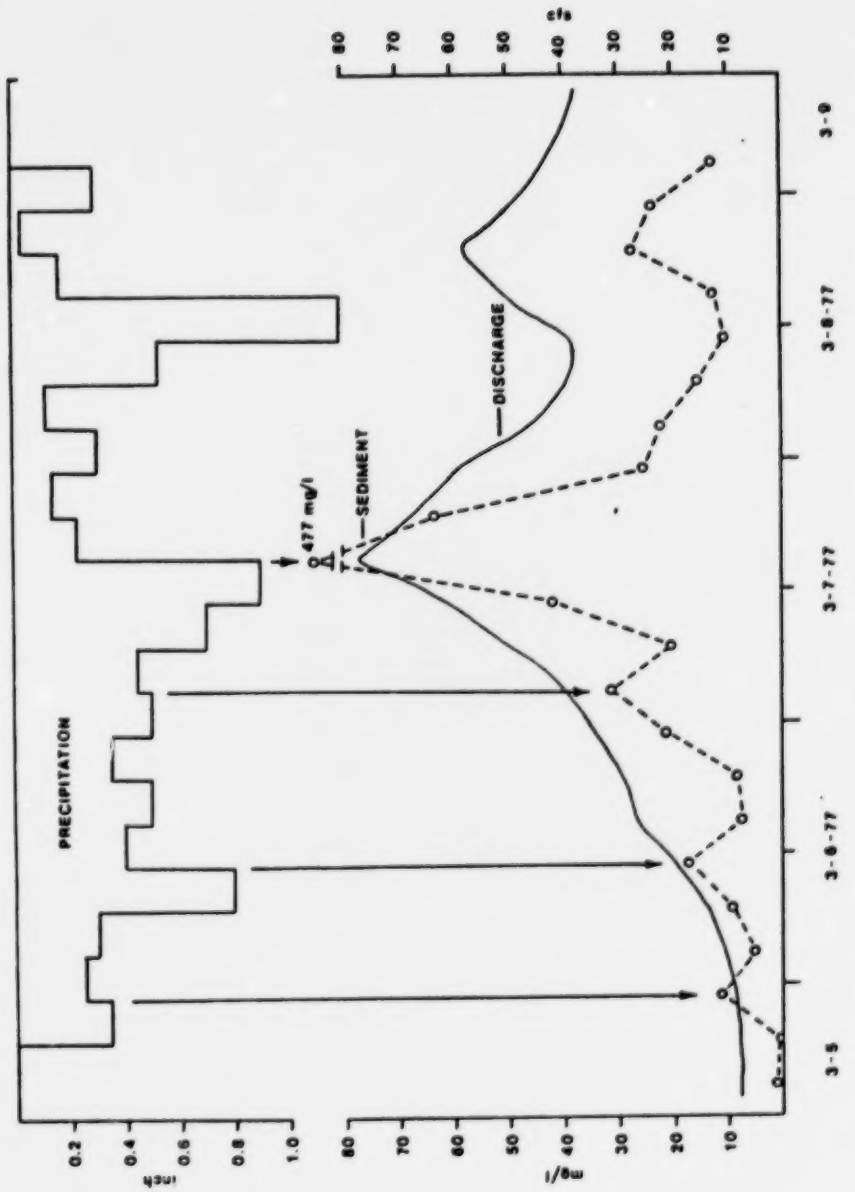

Figure 13. A medium intensity winter storm which occurred during the first inactive period. Fly Creek sediment pulses following rainfall are shown.

Table 1. Turbidity (NTUs), sediment concentration and transport in Fly Creek by date, time, discharge and rain for a late winter storm during a period of no construction activity.

Date	Time	Sediment (NTU)	Sediment (mg/l)	Sediment (lbs.)	Discharge (cfs)	Rain (in.)
3/5/77	1900	less than 1 mg/l		-	8.4	0
	2300	2	11	95	9.6	0.35
3/6	0300	3	5	49	11	.25
	0700	3	9	104	13	.30
	1100	7	17	306	20	.80
	1500	4	7	167	27	.40
	1900	4	8	92	28	.50
	2300	7	21	289	34	.35
3/7	0300	14	31	479	38	.50
	0700	8	20	899	50	.45
	1100	15	42	2,252	60	.70
	1500	130	477	32,909	77	.92
	1900	18	63	3,768	66	.23
	2300	9	25	1,320	59	.14
3/8	0300	7	22	892	45	.31
	0700	5	15	513	38	.12
	1100	4	10	347	39	.53
	1500	6	12	538	50	1.20
	1900	13	27	1,396	58	.17
	2300	8	23	989	49	.03
3/9	0300	4	12	458	42	.30

Creek with 1.62 in. of rain in 8 hours on 3/7. The maximum suspended sediment concentration of 477 mg/l (3/7, 1500 hrs.) coincided with peak discharge (77 cfs) but not the maximum 4-hr. rainfall (0.92 in.) of the 3-day storm. Sources of sediment were not identified, but undoubtedly a failure of either sidecast or cut slope into flowing water contributed the maximum concentration (477 mg/l) and transport rate (4.1 tons/hour).

The maximum 4-hr. rainfall rate (1.20 in.) occurred on 3/8 causing an increase in discharge (58 cfs) and an increase in sediment concentration to 27 mg/l, much less than the sediment transport (0.2 tons/hour) or concentration (477 mg/l) which occurred at peak discharge on 3/7. These data show the dynamic hydrologic condition of the Fly Creek watershed by rapid streamflow response to intense rain and rapid transport of large quantities of sediment. The total sediment transported was 23.7 tons during the 80-hr. storm. Suspended sediment transport rate (in lbs.) increased 15-fold in 4 hours between 1100 and 1500 on 3/7, then declined 37-fold in the next 10 hours.

A year later, an intense storm (1.3 in. in 8 hrs.) on 3/6 and 7, 1978 caused rapid increases in sediment concentration (47 mg/l), transport (0.1 ton/hour), and discharge in Fly Creek (Figure 14). Sediment concentrations and transport declined later in the day (3/7) even as streamflow increased to 20 cfs.

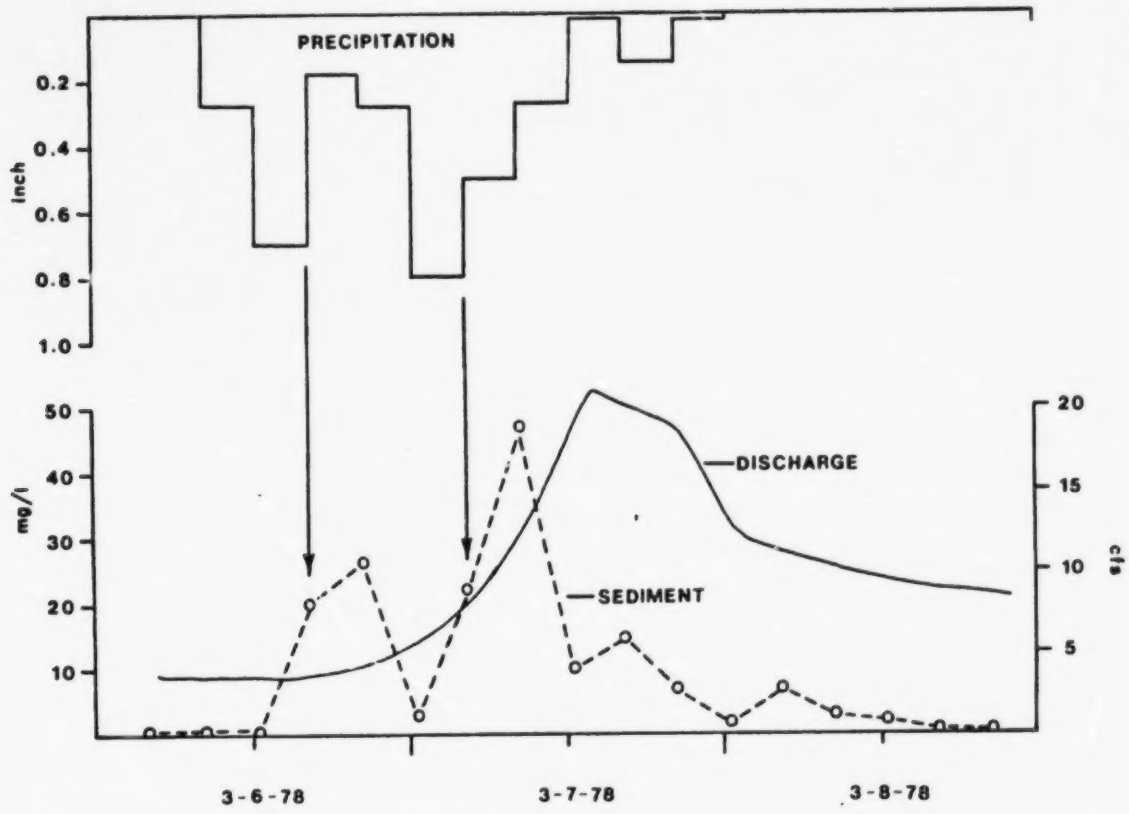

Figure 14. Increases in Fly Creek suspended sediment concentrations resulting from rainfall during the second winter's inactive period.

SEDIMENT, ROAD CONSTRUCTION AND WATER QUALITY STANDARDS

The Water Quality Standards for the State of Washington (WAC, 173-201) limit changes in turbitity to 5 NTUs over background when background turbidity is less than 50 NTUs, or a 10% increase when background turbidity exceeds 50 NTUs for Class A and AA streams. Background turbidities in Fly Creek for storms studied did not exceed 50 NTUs, so the 5 NTU limit was compared with the magnitude and duration of variance from Water Quality Standards by activities during phases of road construction (Table 2). In general, construction work in or close to stream channels induced turbidity which exceeds the Water Quality Standards. The maximum variance during in-channel work was 175 NTUs when excavating an upstream footing, grading and sidecasting for the bridge approach over Fly Creek. This activity (September 1976) caused 9 hours of degradation of water quality (from 2 to 175 NTUs) as the sediment supply was transported. In September 1977, a culvert installation in a tributary of Fly Creek caused turbidity to exceed the Water Quality Standards by 2 to 65 NTUs for 4 hours.

Extended durations of variance in Water Quality Standards were induced by road use. The hauling of rock and right-of-way timber caused turbidity to exceed (1 to 105 NTUs) the Water Quality Standards for about 55 hours in late October 1976. Hauling of right-of-way timber during rain in October 1977 also caused extended (6 to 24 hours) departures (1 to 52 NTUs) from Water Quality Standards.

The maximum variances measured occurred with rain from unknown causes or during periods of no construction activity. These events often were associated with intense rain (9/19,20/77). However, a variance of 445 NTUs occurred between 4:30 and 6:30 a.m. on September 28, 1977 from unknown causes during a period of light rainfall (0.17 in. in 4 hrs.).

Table 2. Magnitude and duration, by activities, of Fly Creek water quality in variance with State standards.

Date	Time[1]	Magnitude of Variance (NTU)	Duration[2] (Hours)	Activity
First Year				
9/16/76	1600	6	1	Blasting rock (Fig. 3)
9/22	1400	2	½	Excavation for bridge footings (Fig. 5)
9/22	1600	2	½	Excavation for bridge footings (Fig. 5)
9/23	1300	2 to 7	4½	Placing footings and bridge span (Fig. 6)
9/24	1030	4 to 27	1	Excavation upstream on bridge
9/24	1630	1 to 9	1	Excavation upstream on bridge
9/27	1030	2 to 175	9	Excavation upstream on bridge and grading and sidecast. (Fig. 6)
10/25	1000	2 to 105	15	Hauling rock - rain (Fig. 8)
10/26	0100	1 to 5	24	Hauling rock (Fig. 8)
10/27	0000	2 to 5	14½	Hauling rock and ROW timber (Fig. 8)
10/31	0330	5 to 140	20	No activity - rain (Fig. 12)
11/14	1300	4 to 23	5	No activity - rain
Second Year				
8/24/77	1500	1	4	No activity - rain (Fig. 9)
8/24	2300	4	4	No activity - rain (Fig. 9)
9/19	1030	23 to 175	12	No activity - rain (Fig. 10)
9/20	0000	12 to 125	24	No activity - rain (Fig. 10)
9/21	0030	2 to 7	2	No activity - rain (Fig. 10)
9/21	0830	5 to 37	2	Hauling rock (Fig. 10)
9/21	1430	1 to 8	2	Hauling rock (Fig. 10)
9/23	0730	1 to 72	14	Unknown (Fig. 10)
9/24	0930	4	2	No activity - rain (Fig. 10)
9/24	1330	16 to 60	4	No activity - rain (Fig. 10)

[1]A 24-hr. clock.

[2]The duration of impact may be less than indicated as minimums are regulated by the sampling interval.

Table 2 cont'd

9/27	1030	5	2	Unknown - rain (Fig. 7)
9/27	2030	4 to 54	4	Unknown - rain (Fig. 7)
9/28	0630	2 to 445	12	Unknown - rain (Fig. 7)
9/29	1300	2 to 65	4	Culvert in Fly Cr. tributary (Fig. 7)
9/29	2100	2	2	Unknown (Fig. 7)
10/ 6	2130	2 to 24	4	Unknown - rain (Fig. 11)
10/11	1800	6 to 65	8	No activity - rain
10/23	0500	1 to 120	20	No activity - rain
10/24	1330	1 to 41	10	Hauling ROW timber - rain
10/25	1130	1 to 52	12	Hauling ROW timber - rain
10/26	0730	2 to 3	6	Hauling ROW timber - rain
10/27	0030	13 to 48	24	Hauling ROW timber - rain
10/29	0830	2 to 11	16	No activity - rain
10/30	0000	1 to 27	16	No activity - rain
11/ 1	0030	8	?	No activity - rain
11/ 2	0000	6 to 22	24	Hauling ROW timber - rain
11/ 3	0000	1 to 5	15½	Hauling ROW timber - rain
11/ 6	1130	2 to 15	8	No activity - rain
1/13/78	1100	3 to 16	8	Hauling ROW timber - rain
1/14	0700	3 to 12	8	No activity - rain
1/16	1100	3 to 34	8	Hauling ROW timber - rain

DISCUSSION AND CONCLUSIONS

Findings of this study confirm the concept that sediment transport processes of forest streams in undisturbed basins are limited in sediment transport by the available supply of sediment. Construction of forest roads disrupts the equilibrium supply-transport conditions by increasing the available supply of sediment for surface erosion, thus, resulting in increased sediment transport, particularly during times of rain and increased streamflow. Maximum increases in concentrations of suspended sediment occurred with rain immediately after the construction activity provided a sediment supply. Sediment transport rates increased with continuing rain and increasing discharge, but frequently concentrations of suspended sediment declined with increasing discharge. A return to equilibrium conditions occurs over time as sediment concentrations and sediment transport declined with ensuing rains as the supply of available sediment from surface soil erosion diminishes--a finding of this study and reported by Fredriksen (1970) and Harris (1977).

Road use by trucks also increased the sediment supply for surface erosion and transport by streams. The largest increase in sediment concentration in Fly Creek (139 mg/l) during light rain (0.44 in./day) exceeded the concentration reported (22 mg/l) for Coal Creek (Wooldridge 1979) for similar rain intensity. Increases during the work day were measured in both studies with usually rapid reduction in sediment concentration when road use terminated.

Mass failures of road cuts and sidecast, particularly in close proximity to the stream, resulted in an increased supply of sediment and transport by Fly Creek. Mass failures occurred randomly in association with intense or often prolonged rains. Maximum suspended concentrations (825 mg/l) occurred due to failures during generally wet periods but reduced streamflow (5 to 15 cfs). The rate sediment was transported by Fly Creek was 0.6 tons per hour.

Mass failures associated with intense prolonged rains caused increased sediment transport (1.1 tons per hour) due to greatly increased discharge (245 cfs). However, sediment concentrations in Fly Creek were much less (67 mg/l). Transport of the sediment supply made available by mass failures is a function of the size of the failure and its location in relation to the stream. Small mass failures will be transported rapidly during increased streamflow, so sediment transport processes will return to equilibrium conditions. Large or numerous mass failures may increase the available sediment supply to the extent that transport processes are limited by stream energy or stream power, a condition where a maximum sediment supply is available for transport at any given discharge rate.

Phases of forest road construction which may potentially contribute sediment to forest streams were grouped by: 1) those in close proximity to streams, and 2) separated from the stream channel in periods with and without rain. Construction activities monitored included: felling and bucking of right-of-way timber, blasting of stumps and rock, yarding and decking of right-of-way logs, initial and final grading of the road, and ballasting and surfacing. Construction activities occurring close to streams or free flowing water, such as culvert and bridge work or grading and filling approaches, may produce sediment without rain. Culvert installations, excavation for bridge footings, and blasting near the stream caused increases in suspended sediment concentration and transport without rain. Grading, backfilling, and surfacing near or over bridges and culverts also deposited soil material directly in flowing water. Concentrations of suspended sediment in streams and quantities of sediment transported were usually small from the above causes and the duration of effect short.

Increases in suspended sediment transport seldom occurred during working hours without rain when construction activities were removed from the stream. Most road construction was conducted during rainless periods; thus, a variety of construction activities took place without rain. Later, rain provided sufficient energy to detach and transport soil particles to streams as surface soil erosion. Identification of the exact source of sediment was not always attempted or possible; however, rains produced surface erosion from newly graded road surfaces, ditch lines, exposed cut and fill slopes, and sidecast or fill close to streams.

This study has placed quantitative values on the magnitude (in NTUs and mg/l) and duration (in hours) of variance in Water Quality Standards caused by various forest road construction activities. The use of a BMP as a temporary substitute for water quality standards under concepts of non-point sources of pollution was quantified by the study, but results are not applicable to other areas. Application of BMPs in forest road construction should minimize the amount of sediment which might potentially become available for transport in or by streams. Obviously, narrower and shorter roads with adequate relief culverts, wasting surface runoff from roads in stable areas, will reduce the sediment supply-transport potential. The environmental or ecological consequences in streams of exposure of aquatic organisms to the concentrations and durations of increased sediment found in this study remain to be identified.

It may be concluded that many phases of forest road construction may increase the sediment supply, thus, altering the equilibrium of sediment supply-transport processes of forest streams. The numerous and intense winter rains of western Washington provide a sufficient energy source to streams to transport the increased sediment supply produced by forest road construction, thus, rapidly returning the basin to a supply-transport

condition similar to the equilibrium processes prior to road construction. Road use will also alter the sediment supply-transport process equilibrium by increasing the available sediment supply. Again, sediment is transported rapidly during rain and increased streamflow and will return quickly to equilibrium conditions during any periods of non-use.

Mass failures associated with the forest road system, induced by prolonged and intense rain, have the greatest potential for long term alteration of the sediment supply-transport process equilibrium. This study was not of sufficient duration to identify the time required for return to equilibrium conditions. However, most studies in forests of the humid West Coast show a return to near pre-road equilibrium sediment supply-transport processes in three to five winters following road construction (Fredriksen 1970, Harris 1977).

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APPENDIX I

DIARY OF CONSTRUCTION ACTIVITIES AND SUSPENDED SEDIMENT MONITORING

The following is a diary of construction activities and suspended sediment monitoring which occurred during the study. Construction periods as well as inactive periods are matched with sediment concentrations and the climatic variables, precipitation, and streamflow. The diary is divided into three sections: construction, ROW timber hauling, and inactivity.

Road Construction

First construction period.

9/8/76 (Wed.) Preparing road bed for bridge approach. Cutting log stringers for temporary bridge across Clearwater River. Construction activities not impacting Fly Creek. Sampling not yet initiated. No rain.

9/14/76 (Tues.) Bridge stringers in place over Clearwater River. Cat has been in river. Initiated sediment sampling although missed stringer installation. .Clearwater River low, 41 cfs; sediment less than 1 mg/l. No rain.

9/15/76 (Wed.) Cats excavating road toward Fly Creek on south side Clearwater River. Clearwater bridge not yet surfaced and equipment is fording river. Clearwater River low; background sediment levels all day (less than 1 mg/l). No rain.

9/16/76 (Thurs.) Continued excavation on road between Clearwater bridge and Fly Creek. Blasting rock outcrop near Fly Creek. Sampling of Fly Creek initiated. Fly Creek clear until 1600, slightly turbid between 1600 and 1900 due to blasting (see Figure 3). Clearwater River low, 26 cfs; sediment less than 1 mg/l. No rain.

Fly Creek

Time	NTU	mg/l	cfs	lbs transported
1600	11	21	2.2	10.4
1700	4	5		2.5
1800	4	9		4.5
1900	4	9		4.5
2000	less than 1 mg/l		2.2	
	Total less background			21.5

9/17/76 (Fri.) Continued road construction between Clearwater River and Fly Creek. Blasting, excavation, earthmoving. Clearwater River low, 25 cfs; background sediment only. Fly Creek 2.1 cfs, sediment less than 1 mg/l. No rain.

9/18/76 (Sat.) No activity, no sampling, no rain.

9/19/76 (Sun.) No activity, no sampling, no rain.

9/20/76 (Mon.) Continued road construction between Clearwater River and Fly Creek. End hauling from rock outcrop and using it to ballast road. Placing earth surfacing on Clearwater River log stringer bridge. Clearwater River low, 22 cfs; background sediment except at 1000--89 NTU, 140 mg/l, 690 lbs--water clear by 1100. Sediment probably due to bridge surfacing (see Figure 4). Fly Creek 1.8 cfs; sediment less than 1 mg/l all day. No rain (see Figure 4).

9/21/76 (Tues.) Site not visited; 0.01 inch rain.

9/22/76 (Wed.) Had surfaced road approaching Clearwater bridge, over bridge, and part way to Fly Creek (on 9/21/76). Started excavation today for Fly Creek log stringer bridge. Clearwater River low, 23 cfs; sediment less than 1 mg/l all day. Fly Creek 2.0 cfs; minor sediment concentrations after 1400 from bridge excavation and rainfall (see Figure 5). Raining lightly--daily total 0.18 inch.

Fly Creek

Time	NTU	mg/l	cfs	lbs transported
1300	less than 1 mg/l		2.0	
1400	7	13		2.9
1430	4	9		2.0
1500	4	6		1.3
1530	5	8		1.8
1600	7	24		5.4
1630	3	3		0.7
1700	2	2		0.4
1730	2	3	1.9	0.4
1800	2	1		0.2
1830	less than 1 mg/l			
	Total less background			14.3

9/23/76 (Thurs.) Placing abutments and stringers on Fly Creek bridge. Clearwater River low, 22 cfs; sediment less than 1 mg/l all day. Fly Creek 1.9 cfs; minor sediment concentrations due to stringer installation (see Figure 6). No rain.

Fly Creek

Time	NTU	mg/l	cfs	lbs transported
1320	less than 1 mg/l		1.9	
1300	8	13		2.8
1330	8	11		2.4
1400-1530	less than 1 mg/l			0.9
1600	12	15		3.2
1630	7	10		2.1
1700	5	10		2.1
1730	6	8		1.7
1800	5	10		2.1
1830	less than 1 mg/l			
	Total less background			16.2

9/24/76 (Fri.) Continued working on Fly Creek bridge, excavating uphill side of bridge. Clearwater River low, 20 cfs; slight but unmeasurable turbidity due to sediment contribution from Fly Creek. Clearwater River clear above confluence. Fly Creek 1.7 cfs; minor sediment concentrations due to bridge construction (see Figure 6). No rain.

Fly Creek

Time	NTU	mg/l	cfs	lbs transported
0930	unknown			1.7
1030	32	57		21.8
1130	9	12		4.6
1230	4	4		1.5
1330	5	6		2.3
1430	4	5		1.9
1530	4	2		0.8
1630	14	22		8.4
1730	6	4		1.5
1830	4	3		1.2
1930	5	4		1.5
2030	5	2		0.8
2130	less than 1 mg/l			
	Total less background			44.1

9/25/76 (Sat.) No activity, no sampling, no rain.

9/26/76 (Sun.) No activity, no sampling, no rain.

9/27/76 (Mon.) Working on bridge over Fly Creek. Excavating road on uphill side of bridge, minor sidecasting. Clearwater River low, 19 cfs; sediment less than 1 mg/l all day. Fly Creek 1.6 cfs; sediment from sidecasting reaching stream (see Figure 6). No rain.

Fly Creek

Time	NTU	mg/l	cfs	lbs transported
0930	less than 1 mg/l		1.6	
1030	32	46		16.2
1130	180	267		96.1
1230	29	37		13.3
1330	22	39		14.0
1430	18	30		11.0
1530	15	21		7.6
1630	9	17		6.1
1730	9	14		5.0
1830	7.5	25		9.0
1930	10	24		8.6
2030	less than 1 mg/l			
	Total less background			185.2

9/28/76 (Tues.) Working on Fly Creek bridge, excavating road uphill from bridge. Placed earth surfacing over log stringers in late afternoon. Clearwater River low, 18.5 cfs; sediment less than 1 mg/l all day. Fly Creek 1.6 cfs, no sediment transported even when surfacing bridge (however, impacts from surfacing may have occurred between samples). No rain.

9/29/76 (Wed.) Continued excavating above Fly Creek bridge and on bench above stream. Yarding ROW timber on bench. Clearwater River low, 17.5 cfs; sediment less than 1 mg/l all day. Fly Creek 1.5 cfs; sediment less than 1 mg/l all day. No rain.

9/30/76 (Thurs.) Continued road construction above Fly Creek bridge and on bench paralleling stream. Yarding ROW timber. Clearwater River low, 16.5 cfs; sediment less than 1 mg/l all day. Fly Creek 1.4 cfs; sediment less than 1 mg/l all day. No rain.

10/1/76 (Fri.) Continued road construction. Clearwater River low, 16 cfs; sediment less than 1 mg/l all day. Fly Creek 1.4 cfs; sediment less than 1 mg/l all day. No rain.

10/2/76 (Sat.) No activity. Clearwater River peaks at 50 cfs from 0.29 inch rain between 0200 and 1200; no sediment above background all day. Fly Creek peaks at 3.8 cfs; no sediment above background all day.

10/3/76 (Sun.) No activity, no sampling, 0.05 inch rain.

10/4/76 (Mon.) Site not visited, no sampling, 0.02 inch rain.

10/5/76 (Tues.) Grading and surfacing road between Clearwater bridge and Fly Creek bridge. Yarding ROW timber between bridges. Clearwater River 23 cfs; sediment less than 1 mg/l all day. Fly Creek 1.6 cfs; sediment less than 1 mg/l all day. Rainfall 0.02 inch.

10/6/76 (Wed.) Continued surfacing road from Clearwater River to bench above Fly Creek. Completed ROW yarding on bench. Clearwater River 22 cfs; sediment less than 1 mg/l all day. Fly Creek 1.5 cfs; sediment less than 1 mg/l all day. No rain.

10/7/76 (Thurs.) Excavating rock outcrop just prior to Fly Creek bridge to bring side slope into design compliance. Side casting material into Fly Creek drainage, but not in water. Clearwater River 21 cfs; sediment less than 1 mg/l all day. Fly Creek 1.5 cfs; sediment less than 1 mg/l all day. No rain.

10/8/76 (Fri.) Continued excavating and sidecasting on rock outcrop just prior to Fly Creek bridge. Clearwater River 24 cfs; sediment less than 1 mg/l all day. Fly Creek 1.6 cfs; sediment less than 1 mg/l all day even though 0.11 inch rain fell between 1400 and 1900.

10/9/76 (Sat.) No activity. Clearwater River 23 cfs, sediment less than 1 mg/l all day. Fly Creek 1.5 cfs; sediment less than 1 mg/l all day. Rainfall 0.18 inch between 1700 and 2400.

10/10/76 (Sun.) No activity. Clearwater River 32 cfs, sediment less than 1 mg/l all day. Fly Creek 2.2 cfs; sediment less than 1 mg/l all day. Rainfall throughout day totaled 0.18 inch.

10/11/76 (Mon.) Continued excavating on rock outcrop at turn before Fly Creek bridge. Clearwater River 33 cfs; sediment less than 1 mg/l all day. Fly Creek 2.3 cfs; sediment less than 1 mg/l all day. Rainfall 0.01 inch.

10/12/76 (Tues.) Continued excavating on turn before Fly Creek. Clearwater River 26 cfs; sediment less than 1 mg/l all day. Fly Creek 1.8 cfs; sediment less than 1 mg/l all day. No rain.

10/13/76 (Wed.) Continued excavating on turn before Fly Creek bridge. Using rock for surfacing and ballast on construction continuing uphill. Clearwater River 24 cfs; sediment less than 1 mg/l all day. Fly Creek 1.6 cfs; sediment less than 1 mg/l all day. No rain.

10/14/76 (Thurs.) Continued excavating rock outcrop on turn before Fly Creek bridge. Using rock for surfacing, hauling across Fly Creek bridge and up drainage to continued construction. Clearwater River 23 cfs; sediment less than 1 mg/l all day. Fly Creek 1.5 cfs; sediment less than 1 mg/l all day. No rain.

10/15/76 (Fri.) Continued excavating rock outcrop on turn before Fly Creek bridge. Using rock for surfacing, hauling across Clearwater River bridge. Clearwater River 22 cfs; sediment less than 1 mg/l all day. Fly Creek 1.5 cfs; sediment less than 1 mg/l all day. No rain.

10/16/76 (Sat.) No activity. Clearwater River 22 cfs; sediment less than 1 mg/l all day. Fly Creek 1.4 cfs; sediment less than 1 mg/l all day. No rain.

10/17/76 (Sun.) No activity. Clearwater River 21 cfs; sediment less than 1 mg/l all day. Fly Creek 1.4 cfs; sediment less than 1 mg/l all day. No rain.

10/18/76 (Mon.) Hauling rock from Fly Bridge outcrop, up road for surfacing. Clearwater River 20 cfs; sediment less than 1 mg/l all day. Fly Creek 1.4 cfs; sediment less than 1 mg/l all day. No rain.

10/19/76 (Tues.) Excavating and yarding ROW timber on flats beyond and uphill from Fly Creek bridge. Hauling rock from outcrop for surfacing and ballast. Clearwater 20 cfs; sediment less than 1 mg/l all day. Fly Creek 1.3 cfs; sediment less than 1 mg/l all day. No rain.

10/20/76 (Wed.) Excavation and construction continues uphill from Fly Creek bridge. Clearwater River 19 cfs; sediment less than 1 mg/l all day. Fly Creek 1.3 cfs; sediment less than 1 mg/l all day. No rain.

10/21/76 (Thurs.) Continued uphill construction. Clearwater River 19 cfs; sediment less than 1 mg/l all day. Fly Creek 1.3 cfs; sediment less than 1 mg/l all day. No rain.

10/22/76 (Fri.) Continued construction uphill. Clearwater River 19 cfs; sediment less than 1 mg/l all day. Fly Creek 1.3 cfs; sediment less than 1 mg/l all day. No rain.

10/23/76 (Sat.) No activity. Clearwater River 19 cfs; sediment less than 1 mg/l all day. Fly Creek 1.3 cfs; sediment less than 1 mg/l all day. Rainfall 0.03 inch.

10/24/76 (Sun.) No activity. No sampling. Clearwater River peaked at 81 cfs from rainfall of 1.13 inch. Fly Creek peaked at 6.1 cfs. Sediment levels unknown.

10/25/76 (Mon.) Hauling rock from outcrop up to flats for surfacing. Clearwater River peaked at 220 cfs from rainfall of 0.44 inch. Fly Creek peaked at 21.0 cfs (see Figure 8).

Fly Creek

Time	NTU	mg/l	cfs	lbs transported
0900	Sampling not yet restarted			
1000	105	131	21.0	618.6
1100	110	139	20.7	647.0
1200	48	54	20.5	248.9
1300	32	29	20.0	130.5
1400	52	61	18.6	255.1
1500	30	23	17.4	89.9
1600	18	11	16.9	41.9
1700	14	10	15.8	35.5
1800	10	8	14.9	26.9
1900	9	3	14.2	9.7
2000	7	2	13.6	6.2
2100	6	4	12.9	11.7
2200	6	1	12.4	2.9
2300	6	1	12.0	2.7
2400	7	2	11.5	5.3
	Total less background			2131.2

During this same time period, 7937 lbs suspended sediment was transported into the study area by the Clearwater River. The Fly Creek addition of 2131 lbs to the Clearwater was not measurable as an increased concentration. Range Clearwater River 1-34 mg/l.

10/26/76 (Tues.) Hauling rock from outcrop and constructing truck turnout near Clearwater bridge. Clearwater River 105 cfs; sediment range 2-17 mg/l. Rainfall 0.02 inch (see Figure 8).

Fly Creek

Time	NTU	mg/l	cfs	lbs transported
0100	7	3	11.1	7.5
0200	8	3	10.6	7.1
0300	7	4	10.2	9.3
0400	6	1	9.9	2.2
0500	6	2	9.7	4.4
0600	6	2	9.4	4.2
0700	5	1	9.2	2.0
0800	6	1	9.0	2.0
0900	5	1	8.8	2.0
1000	5	4	8.6	7.7
1100	4	2	8.5	3.8
1200	5	4	8.3	7.5
1300	5	2	8.1	3.8
1430	8	2	7.8	5.3
1730	10	2	7.5	10.1
2030	10	1	7.1	4.9
2330	9	2	6.8	9.3
	Total less background			70.1

10/27/76 (Wed.) Construction halted. Preparing to haul out ROW timber. Clearwater River 78 cfs; sediment range 1-20 mg/l. No rain (see Figure 8).

Fly Creek

Time	NTU	mg/l	cfs	lbs transported
0230	10	3	6.4	13.0
0530	8	3	6.1	12.4
0830	7	8	5.8	31.3
1130	9	3	5.6	11.2
1430	9	2	5.2	7.1
1730	Less than 1 mg/l			
	Total less background			52.0

Second-year construction period

6/28/77 (Tues.) to 7/3/77 (Sun.) Falling ROW timber. Clearwater River 28 cfs, dropping to 25 cfs but rising again to 29 cfs; no sediment transported above background during entire period. Fly Creek 2 cfs, dropping to 1.7 cfs but rising again to 2.0 cfs; no sediment transported above background level. Rainfall 0.51 inch during Saturday and Sunday.

7/4/77 (Mon.) to 7/6/77 (Wed.) Site not visited, no sampling. Rainfall 0.36 inch from 7/4 through 7/5/77.

7/7/77 (Thurs.) to 7/12/77 (Tues.) No activity at study end of road. Rather than continue road construction from bottom end as expected, contractor is constructing road from ridgeline downhill to eventually connect with road constructed last year. Approximately 6000 ft of new construction is required before road will enter study area and impact Fly Creek. Clearwater River 26 cfs on 7/11/77 from 0.28 inch rain, drops to 24 cfs on 7/12. Fly creek 1.8 cfs dropping to 1.5 cfs by 7/10, rising to 2.2 cfs on 7/11, drops to 1.7 cfs on 7/12. No sediment transported above background during this period. Rainfall 0.38 inch.

7/13/77 (Wed.) to 7/25/77 (Mon.) No sampling, construction activity confined to ridgeline, not impacting Fly Creek. Streams low, little rain.

7/26/77 (Tues.) to 8/22/77 (Mon.) Road construction continues on ridgeline, ROW timber hauled out upper end. No noticeable impact on Fly Creek. Clearwater River drops from 19 to 13 cfs during this period. Fly Creek drops from 1.3 to 0.9 cfs; sediment less than 1 mg/l. Rainfall in late July totaled 0.65 inch, no rain in August.

8/23/77 (Tues.) No activity, no sampling. Clearwater River rises from 13 to 34 cfs. Fly Creek rises from 0.9 to 2.4 cfs. Rainfall 0.97 inch.

8/24/77 (Wed.) No activity. Clearwater River rises from 24 to 171 cfs. Fly Creek rises from 1.7 to 15.2 cfs. Rainfall 1.77 inch (see Figure 9).

Fly Creek

Time	NTU	mg/l	cfs	in. precip.	lbs transported
0700	less than 1	mg/l	1.7	0.10	1.5
1100	3	3	1.7	0.32	3.8
1500	6	20	5.7	0.40	100.3
1900	3	5	5.7	0.66	25.6
2300	9	30	14.8	0.30	393.1
	Total less background				511.9

8/25/77 (Thurs.) No activity. Clearwater River rises again to peak at 260 cfs. Fly Creek peaks at 26.1 cfs. Rainfall 1.32 inch (see Figure 9).

Fly Creek

Time	NTU	mg/l	cfs	in. precip.	lbs transported
0300	4	7	8.6	0.34	57.3
0700	5	8	7.8	0.10	52.7
1100	3	3	6.1	0.22	13.7
1500	3	5	8.0	0.16	35.3
1900	3	5	20.4	0.30	90.0
2300	2	2	22.9	0.20	51.6
		Total less background			268.3

8/26/77 (Fri.) No activity. Clearwater River falling from 204 to 62 cfs. Fly Creek falling from 19.7 to 4.5 cfs. Rainfall 0.04 inch (see Figure 9).

Fly Creek

Time	NTU	mg/l	cfs	in. precip.	lbs transported
0300	3	2	16.6	0	37.3
0700	2	5	11.7	0	52.7
1100	2	1	8.3	0	3.8
1500	2	1	5.6	0.04	2.4
1900	2	3	5.0	0	11.2
2300	2	2	4.6	0	10.4
		Total less background			93.7

8/27/77 (Sat.) No activity. Clearwater River dropped from 60 to 46 cfs. Fly Creek dropped from 4.4 to 3.2 cfs; sediment less than 1 mg/l all day. Rainfall 0.03 inch.

8/28/77 (Sun.) No activity. Clearwater River rises to 73 cfs. Fly Creek rises to 5.4 cfs; sediment less than 1 mg/l all day. Rainfall 0.67 inch.

8/29/77 (Mon.) to 8/31/77 (Wed.) Construction continues downhill from ridgeline. Clearwater River dropped from 69 to 49 cfs. Fly Creek dropped from 5.1 to 3.4 cfs; no sediment above background transported this period. Rainfall 0.20 inch.

9/1/77 (Thurs.) to 9/12/77 (Mon.) Construction sporadic. Clearwater River peaks at 164 cfs on 9/2/77 and drops to 39 cfs by end of period. Fly Creek peaks at 14.4 cfs. Rainfall 0.95 inch on 9/2/77, 0.15 inch on 9/3/77 and 0.55 inch on 9/4/77. No rainfall during remaining period. Although heavy rain on 9/2/77, no sediment above background transported during entire period.

9/13/77 (Tues.) to 9/18/77 (Sun.) No data collected.

9/19/77 (Mon.) No activity. Upper and lower road sections have been joined. Raining hard and water already turbid when sampling initiated. Clearwater River rises from 53 cfs and peaks at 164 cfs. Fly Creek rises from 3.7 cfs, peaking at 14.4 cfs; transported sediment from area where road sections connect, specifically, swampy area where road terminated previous year (see Figure 10). Rainfall 2.20 inch.

Fly Creek

Time	NTU	mg/l	cfs	in. precip.	lbs transported
0030			3.7	0.04	
0230	"no samples"		4.4	0.10	
0430			4.7	0.08	
0630			5.9	0.30	"unknown"
0830			12.4	0.36	
1030	180	231	14.4	0.22	1496.1
1230	100	53	13.3	0.08	316.4
1430	82	49	10.8	0.24	235.7
1630	84	55	11.1	0.20	273.4
1830	170	272	14.4	0.48	1763.5
2030	56	44	14.4	0.04	287.5
2230	28	22	9.9	0.06	99.2

9/20/77 (Tues.) Assume no activity due to rain. Clearwater River at 80 cfs rises slightly then drops to 51 cfs. Fly Creek drops from 6.0 to 4.0 cfs (see Figure 10). Rainfall 1.19 inch.

Fly Creek

Time	NTU	mg/l	cfs	in. precip.	lbs transported
0030	16	13	5.9	0.01	35.3
0230	130	165	5.9	0.48	439.2
0430	43	25	5.9	0.04	65.9
0630	24	18	6.2	0.18	49.8
0830	20	11	5.5	0.02	27.6
1030	75	49	4.9	0.22	107.4
1230	41	27	4.9	0.05	58.9
1430	34	24	4.9	0.02	53.8
1630	92	95	4.5	0.04	192.9
1830	40	13	4.4	0.03	26.5
2030	41	49	4.4	0.06	96.3
2230	17	13	4.0	0.03	23.8
		Total less background			1163.8

9/21/77 (Wed.) Laying ballast on road, ballast from rock pit near Fly Creek. Clearwater River dropped from 50 to 38 cfs. Fly Creek dropped from 3.5 to 2.6 cfs (see Figure 10). No rain.

Fly Creek

Time	NTU	mg/l	cfs	in. precip.	lbs transported
0030	12	4	3.5	0	6.9
0230	7	2	3.4		3.3
0430	5	2	3.1		3.1
0630	5	2	2.7		2.7
0830	42	44	2.6		51.6
1030	10	9			10.4
1230	3	4			5.1
1430	13	4			5.1
1630	6	9	2.6		10.4
		Total less background			97.9

9/22/77 (Thurs.) Continued ballasting road, also placing fill south side new Clearwater River bridge. Fly Creek rising toward day's end from minor rainfall of 0.03 inch; maximum sediment concentration 11 mg/l (see Figure 10).

9/23/77 (Fri.) Road activity unknown. Rainfall 0.62 inch (see Figure 10)

Fly Creek

Time	NTU	mg/l	cfs	in. precip.	lbs transported
0130	4	6	4.9	0	14.3
0330	4	2		0	4.6
0530	3	0		0	0
0730	10	4	5.0	0.04	9.4
0930	29	27	5.5	0.16	67.0
1130	75	78	6.7	0.26	234.8
1330	77	72	9.8	0.14	315.5
1530	29	17	11.0	0.01	83.1
1730	16	6	9.6	0.01	27.1
1930	9	4	8.6	0	16.3
2130	6	0	7.8	0	0
2330	5	2	7.3	0	6.8
		Total less background			759.9

9/24/77 (Sat.) No activity. Rainfall 0.96 inch (see Figure 10).

Fly Creek

Time	NTU	mg/l	cfs	in. precip.	lbs transported
0130	4	2	6.8	0	6.4
0330	3	2	6.5	0	6.2
0530	4	2	6.4	0	6.0
0730	3	0	6.2	0.03	0
0930	9	4	6.3	0.02	11.9
1130	4	2	6.4	0	6.0
1330	65	79	7.6	0.18	271.2
1530	20	17	8.2	0.12	62.0
1730	35	23	9.1	0.13	95.0
1930	"end sampling"		10.8	0.23	
2130			14.4	0.16	"unknown"
2330			14.4	0.09	

9/25/77 (Sun.) No activity, no sampling. Rainfall 0.28 inch.

9/26/77 (Mon.) Placing fill for approaches to permanent Clearwater River bridge. Excavating fill from bank 100 yards north of bridge. Work activities not impacting Fly Creek (see Figure 7). No rain.

Fly Creek

Time	NTU	mg/l	cfs	in. precip.	lbs transported
1030	3	2	8.7	0	7.9
1230	3	2	8.5		7.9
1430	2	2	8.4		7.9
1630	2	2	8.2		7.5
1830	2	0	8.1		0
2030	3	6	7.9		22.1
2230	2	2	7.7		7.3
					47.0

Total less background

9/27/77 (Tues.) Activity unknown, construction continues (see Figure 7) Rainfall 0.19 inch.

Fly Creek

Time	NTU	mg/l	cfs	in. precip.	lbs transported
0030	2	4	7.6	0	14.3
0230	2	2	7.4	0	7.1
0430	2	2	7.3	0	6.8
0630	2	2	7.1	0	6.4
0830	2	2	7.0	0	6.6
1030	10	16	6.8	0	50.3
1230	3	4	6.7	0	12.6
1430	2	4	6.5	0	11.9
1630	3	4	6.5	0.01	12.4
1830	3	0	6.4	0.11	0
2030	59	49	6.3	0.07	138.7
2230	9	4	6.4	0	12.1
	Total less background				260.8

9/28/77 (Wed.) Construction continues, (see Figure 7). Rainfall 0.92 inch.

Fly Creek

Time	NTU	mg/l	cfs	in. precip.	lbs transported
0030	8	8	6.4	0	23.8
0230	3	0	6.3	0	0
0430	4	0	6.3	0.03	0
0630	450	825	6.2	0.14	2301.2
0830	41	42	6.3	0	118.2
1030	15	15	6.3	0.01	41.9
1230	7	6	6.1	0	17.2
1430	17	17	6.0	0.30	44.8
1630	13	19	5.9	0.18	49.4
1830	"end sampling"		5.9	0.26	
2030			6.0	0	"unknown"
2230			6.2	0	

9/29/77 (Thurs.) Installing cross drain culverts beyond Fly Creek bridge. One culvert is minor Fly Creek tributary; sediment transported by Fly Creek due to culvert installation (see Figure 7). No rain.

Fly Creek

Time	NTU	mg/l	cfs	in. precip.	lbs transported
0100			6.0	0	
0300			5.9		
0500			5.7		
0700			5.6		
0900	"no samples"		5.5		"unknown"
1100			5.4		
1300	70	74	5.2		173.1
1500	42	51	5.0		114.2
1700	7	7	5.9		15.2
1900	4	7	4.9		15.2
2100	7	12	4.8		24.9
2300	5	5	4.8		9.9
				Total less background,	352.5

9/30/77 (Fri.) Continued construction, exact activity unknown, probably surfacing. No rain. (see Figure 7)

Fly Creek

Time	NTU	mg/l	cfs	in. precip.	lbs transported
0100	6	12	4.7	0	24.5
0300	3	2			4.9
0500	3	2	4.6		4.6
0700	4	5			9.7
0900	3	2			6.0
1100	4	7	4.5		13.9
1300	5	5			9.3
1500	3	5	4.4		9.0
1700	4	5			9.0
1900	3	2	4.3		4.4
2100	3	0			0
2300	2	2			4.4
				Total less background	91.9

10/1/77 (Sat.) to 10/2/77 (Sun.) No activity. Rainfall 0.06 inch. Fly Creek sediment level remained less than 2 mg/l.

10/3/77 (Mon.) to 10/5/77 (Wed.) Finishing surfacing. No rain during period. Fly Creek dropped from 4.5 to 3.7 cfs. Fly Creek sediment level near background, 2 mg/l or less.

10/6/77 (Thurs.) Small cat cleaning and grading road directly above Fly Creek bridge. Fly Creek turbidity originating in swampy area drained by recently installed culvert and from end haul waste area (see Figure 11). Rainfall 0.51 inch.

Fly Creek

Time	NTU	mg/l	cfs	in. precip.	lbs transported
0930	2	2	3.7	0.04	3.0
1330	4	4	3.7	0.05	6.0
1730	3	2	3.7	0.13	3.0
2130	29	19	4.4	0.28	34.1
0130	7	2	4.5	0.01	3.7
		Total less background			46.0

10/7/77 (Fri.) Construction for all practical purposes completed. Fly Creek dropped from 4.5 to 3.6 cfs. No sediment transported by Fly Creek above background level. No rain.

Right of Way Timber Hauling

First year truck hauling.

Following termination of construction, ROW timber hauling was preceded by a short inactive period. This inactive period is included here as part of the hauling period.

10/28/76 (Thurs.) No activity. Clearwater River 86 cfs/ sediment less than 1 mg/l all day. Fly Creek 6.4 cfs, sediment less than 1 mg/l all day. No rain.

10/29/76 (Fri.) No activity. Clearwater River 65 cfs; sediment less than 1 mg/l all day. Fly Creek 4.7 cfs; sediment less than 1 mg/l all day. No rain.

10/30/76 (Sat.) No activity. Clearwater River rises from 60 to 319 cfs due to 0.65 inch rain; sediment remains near background level. Fly Creek rises from 4 to 35 cfs; sediment concentration rises from 1 to 75 mg/l between 2000 and 2400. Transports 1876 lbs above background (see Figure 12). Rainfall 0.65 inch between 2000 and 2400.

10/31/76 (Sun.) No activity. Clearwater River continues to rise, peaking at 415 cfs from an additional 1.22 inch rain; sediment concentration varies between 1 and 24 mg/l. Fly Creek peaks at 50 cfs (see Figure A4).

Fly Creek

Time	NTU	mg/l	cfs	in. precip.	lbs transported
0330	145	208	43	0.70	8045
0730	30	31	43	0.30	1199
1130	16	15	26	0.15	351
1530	14	11	21	0.05	207
1930	11	8	18	0.02	130
2330	10	8	15	0	112
		Total less background			9967

11/1/76 (Mon.) to 11/7/76 (Sun.) No activity, relatively rainless period, no sampling.

11/8/76 (Mon.) Hauling ROW timber, road muddy. Clearwater River 50 cfs; sediment less than 1 mg/l all day. Fly Creek 3.5 cfs; sediment less than 1 mg/l all day. No rain.

11/9/76 (Tues.) to 11/13/76 (Sat.) Hauling ROW timber, road muddy. Clearwater River 49 cfs dropping to 34 cfs; sediment less than 1 mg/l. Fly Creek dropped from 3.4 to 2.4 cfs; sediment less than 1 mg/l. No rain.

11/14/76 (Sun.) No activity. Clearwater River peaks at 103 cfs from 0.43 inch of evening rainfall; sediment concentration in excess of 37 mg/l. Fly Creek peaks at 8.1 cfs.

Fly Creek

Time	NTU	mg/l	cfs
1100	less than 1 mg/l		2.4
1300	9	5	2.4
1500	13	6	2.5
1700	28	22	3.3
1800	"end sampling"		

11/15/76 (Mon.) to 11/18/76 (Thurs.) Site not visited, no sampling. Rainfall during period 1.94 inch.

11/19/76 (Fri.) to 11/23/76 (Tues.) No activity. ROW timber hauling complete. Clearwater River dropped from 122 to 60 cfs; sediment less than 1 mg/l. Fly Creek dropped from 10 to 4 cfs; sediment less than 1 mg/l. Rainfall during period 0.40 inch.

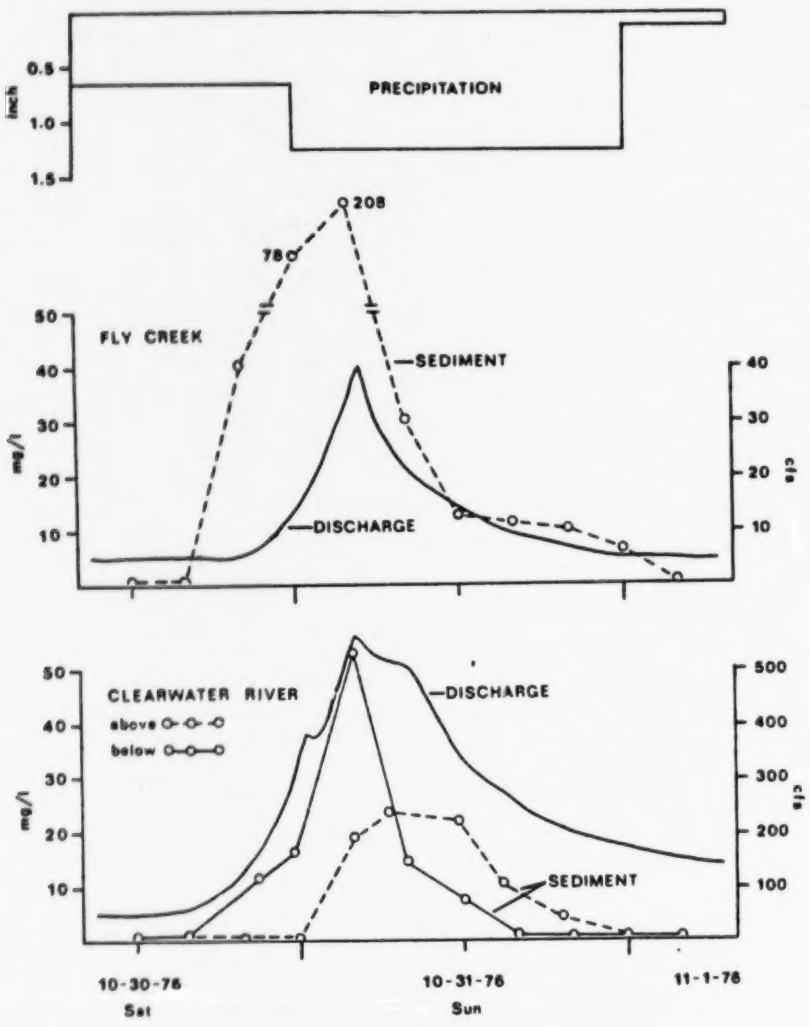

Figure A1. First major storm following termination of first year's road construction. Storm occurred during an inactive period prior to hauling of right-of-way timber. Sediment concentrations in both Fly Creek and the Clearwater River are shown. Clearwater River concentrations above the treatment area are contrasted with those occurring downstream, below the confluence of Fly Creek.

Second year truck hauling.

Construction the second year was completed on 10/10/77 and was followed by a period of sporadic ROW timber hauling. A small, 10 acre clearcut located on the ridgeline near the roads midpoint was included in the road contract to defray part of the construction costs. Timber from this logging was truck hauled along with the ROW timber during this period.

10/11/77 (Tues.) to 10/16/77 (Sun.) No activity. Fly Creek dropped from 3.7 to 3.4 cfs even though 0.52 inch rain on 10/12/77. Total rainfall 0.70 inch.

Fly Creek

Time	NTU	mg/l	cfs	in. precip.	lbs transported
1000	less than 1 mg/l		3.7	0	
1400	2	1		0.16	3
1800	70	68		0.32	226
2200	11	2		0.04	7
0200	less than 1 mg/l			0	
	Total less background				231.3

10/17/77 (Mon.) to 10/18/77 (Tues.) No sampling.

10/19/77 (Wed.) Hauling ROW timber downhill across bridges and out Clearwater mainline. Fly Creek 3.4 cfs; sediment less than 1 mg/l all day. No rain.

10/20/77 (Thurs.) Continued hauling ROW timber. Fly Creek 3.0 cfs; sediment less than 1 mg/l all day. No rain.

10/21/77 (Fri.) Continued hauling ROW timber. Fly Creek 2.5 cfs; sediment less than 1 mg/l all day. Rainfall 0.39 inch during morning and evening, no rain during working hours.

10/22/77 (Sat.) No activity. Fly Creek rises slightly from morning rain only to drop again during day, mean flow 2.7 cfs. No sediment above background concentrations all day. Rainfall 0.30 inch.

10/23/77 (Sun.) No activity. Fly Creek rises to early morning peak of 18.3 cfs from major storm starting at midnight. Rainfall 2.59 inch.

Fly Creek

Time	NTU	mg/l	cfs	in. precip.	lbs transported
0100	"malfunction"		2.7	0.40	
0500	125	277	18.3	1.58	4559
0900	25	24	1.8	0.07	39
1300	27	31	1.7	0.50	47
1700	9	12		0.04	18
2100	6	15		0	8
0100	3	1		0	2

10/24/77 (Mon.) Continued hauling ROW timber, heavy traffic. Solleks River water level recorder not working properly, no discharge estimates possible. Rainfall 1.64 inch.

Fly Creek

Time	NTU	mg/l	in. precip.
1130	"no samples"		1.10
1330	46	.83	0.44
1530	19	24	0.03
1730	9	19	0
1930	7	15	0
2130	23	34	0.03
2330	6	6	0.04

10/25/77 (Tues.) Continued hauling ROW timber. No discharge records. Rainfall 1.48 inch.

Fly Creek

Time	NTU	mg/l	in. precip.
0130	3	2	0
0330	5	6	0
0530	3	2	0.01
0730	3	2	0.02
0930	5	6	0.13
1130	56	71	0.55
1330	57	73	0.32
1530	29	45	0.10
1730	7	15	0
1930	54	90	0.19
2130	9	15	0.16
2330	6	13	0

10/26/77 (Wed.) Continued hauling ROW timber. No discharge records. Rainfall 0.35 inch.

Fly Creek

Time	NTU	mg/l	in. precip.
0130	5	4	0.16
0330	4	2	0.03
0530	3	9	0.03
0730	7	9	0.08
0930	8	9	0.04
1130	7	9	0.03
1330	3	4	0
1530	3	2	0.01
1730	3	2	0
1930	2	2	0
2130	1	1	0

10/27/77 (Thurs.) Continued hauling ROW timber. No discharge records, sediment less than 1 mg/l all day. No rain.

10/28/77 (Fri.) Continued hauling ROW timber. Partial discharge records. Rainfall 3.12 inch.

Fly Creek

Time	NTU	mg/l	cfs	in. precip.	lbs transported
0030	less than 1 mg/l			0.02	
0430	21	21		0.28	
0830	53	64		0.76	
1230	52	66	14	0.90	831
1630	39	52	27	0.58	1263
2030	18	23	34	0.58	703

10/29/77 (Sat.) No activity. Fly Creek rises from 25 to 122 cfs (see Figure 12). Rainfall 2.67 inch.

Fly Creek

Time	NTU	mg/l	cfs	in. precip.	lbs transported
0030	6	13	35	0.14	409
0430	5	4	31	0.20	112
0830	7	13	31	0.28	362
1230	7	11	38	0.38	376
1630	13	15	39	0.42	526
2030	16	21	67	0.62	1266
0030	16	28	120	0.63	3022
		Total less background			5928

10/30/77 (Sun.) No activity. Fly Creek peaks at 245 cfs. (see Figure 12). Rainfall 1.63 inch.

Fly Creek

Time	NTU	mg/l	cfs	in. precip.	lbs transported
0430	32	67	145	0.67	8739
0830	16	24	210	0.60	4533
1230	8	21	122	0.16	2304
1630	6	17	93	0.09	1422
2030	5	17	64	0.06	979
0030	4	13	37	0.05	433
				Total less background	9.04 tons

10/31/77 (Mon.) Continued hauling ROW timber. Fly Creek drops from 38 to 8.3 cfs (see Figure 12). Rainfall 0.54".

Fly Creek

Time	NTU	mg/l	cfs.	in. precip.	lbs transported
0030	4	12	35	0	378
0430	4	12	26	0.13	281
0830	3	2	20	0.07	36
1230	3	2	15	0	27
1630	2	0	11	0	0
2030	2	2	9	0.02	16
0030	13	6	8	0.32	43
				Total less background	727

11/1/77 (Tue.) Continued hauling ROW timber. No sampling. Major winter storm, Fly Creek exceeds 200 cfs from rainfall of 5.91 inch.

11/2/77 (Wed.) Continued hauling ROW timber. Sampling initiated at 1530. Rainfall 0.74 inch.

Fly Creek

Time	NTU	mg/l	cfs	in. precip.	lbs transported
1130	no sample				
1530	27	48	47	0.06	2029
1930	13	37	28	0.09	932
2330	11	27	20	0	486

11/3/77 (Thurs.) Continued hauling ROW timber. Fly Creek dropped from 19 to 3 cfs; sediment concentrations higher than background all day even though no rain.

Fly Creek

Time	NTU	mg/l	cfs	in. precip.	lbs transported
0330	10	22	14	0	277
0730	7	17	9.5		145
1130	6	20	6.5		117
1530	6	17	4.7		72
1930	5	13	3.8		44
2330	4	13	2.9		34
		Total less background			665

11/4/77 (Fri.) Continued hauling ROW timber. Fly Creek dropped from 2.7 to 1 cfs; sediment level maintained near 8 mg/l, 64 lbs suspended sediment transported above background level. Rainfall 0.12 inch.

11/5/77 (Sat.) No activity. Fly Creek 1 cfs; sediment concentration varies between 2 and 8 mg/l. No rain.

11/6/77 (Sun.) No activity. Fly Creek rises to 8.6 cfs from rainfall of 1.11 inch.

Fly Creek

Time	NTU	mg/l	cfs	in. precip.	lbs transported
0330	3	6	0.5	0	3
0730	3	4	0.4	0.06	1
1130	18	22	0.5	0.30	10
1530	20	19	1.0	0.40	17
1930	7	4	7.5	0.26	27
2330	4	4	3.4	0.09	12
		Total less background			65

11/7/77 (Mon.) to 1/12/78 (Thurs.) Intermittent hauling of ROW timber. No sampling during this period.

1/13/78 (Fri.) Hauling ROW timber downhill and across Clearwater River bridge. Road very muddy and rutted from truck traffic. Fly Creek 11 cfs; sampling initiated at 1100.

Fly Creek

Time	NTU	mg/l	cfs	in. precip.	lbs transported
1100	8	28	11.1	--	280
1500	21	27	11.9	0.22	289
1900	11	25	11.7	0.16	263
2300	2	6	11.4	0.07	62

1/14/78 (Sat.) to 1/15/78 (Sun.) No activity. Rainfall 1.06 inch.

Fly Creek

Time	NTU	mg/l	cfs	in. precip.	lbs transported
0300	3	17	11.0	0.05	168
0700	8	22	11.5	0.16	228
1100	17	27	14.3	0.80	347
1500	3	19	13.3	0.02	227
1900	2	17	12.1	0	185
2300	3	6	11.5	0	62
0300	3	6	11.0	0	59
0700	5	8	10.8	0.03	78
1100	2	6	10.5	0	57
1500	4	6	10.1	0	55
1900	2	14	9.8	0	123
2300	2	3	9.7	0	26
			Total less background		1554

1/16/78 (Mon.) to 1/17/78 (Tues.) Continued hauling ROW timber. Last period of sampling prior to winter inactivity.

Fly Creek

Time	NTU	mg/l	cfs	in. precip.	lbs transported
0300	2	6	9.4	0	51
0700	2	11	9.2	0.09	91
1100	8	14	9.4	0.21	118
1500	39	54	9.6	0.12	466
1900	4	14	10.0	0.14	126
2300	2	3	9.4	0	25
0300	2	3	9.0	0	24
0700	2	17	8.6	0	132
1100	2	17	8.5	0.01	130
1500	3	3	8.3	0	22
1900	2	17	8.2	0	125
2300	2	19	8.0	0.01	137
			Total less background		1398

Winter inactivity

First winter

Suspended sediment sampling was sporadic during the winter, inactive period. Freezing weather and snow made access difficult at times. The following diary is not inclusive, only dates of actual sampling are presented.

11/24/76 to 11/28/76 Sampled at 4-hour interval. Clearwater River peaked at 146 cfs on 11/24/76, dropped to 56 cfs by end of period. Sediment concentrations between 0 and 8 mg/l on 11/24/76, sediment less than 1 mg/l on all other days. Concentrations of Clearwater River samples above treatment often greater than concentrations below treatment. Fly Creek peaked at 12.5 cfs, dropped to 4.1 cfs by end of period. Rainfall 1.18 inch.

Fly Creek

	Time	NTU	mg/l	cfs	in. precip.	lbs transported
	0630	less than 1	mg/l	4.3	0	
	1030	7	12	4.5	0.23	49
	1430	7	5	7.0	0.55	31
	1830	4	6	11.0	0.28	59
	2230	6	6	8.6	0.09	46
11/25/78	0230	4	3	7.4	0	20
	0430	less than 1	mg/l	7.0	0	
				Total less background		190

12/2/76 to 12/6/76 Sampled at 4-hour interval. Fly Creek discharge 2-3 cfs; sediment less than 1 mg/l all period. Clearwater River sediment concentrations also less than 1 mg/l during entire period. Rainfall 0.79 inch.

12/7/76 to 12/8/76 Sampled at 2-hour interval. Fly Creek reached 41 cfs on 12/8/76; highest turbidity was 29 NTU (see Figure A2). Samples not filtered for mg/l. Clearwater River peaked at 357 cfs; sediment varied between 0 and 36 mg/l. Rainfall 1.16 inch.

12/9/76 to 12/14/76 Sampled at 4-hour interval. Clearwater River mean flow 194 cfs; sediment less than 1 mg/l all period. Fly Creek mean flow 18 cfs; sediment less than 1 mg/l all period. Rainfall 1.53 inch.

12/22/76 to 12/26/76 Sampled at 4-hour interval. Major storm on 12/25/76 and 12/26/76. Clearwater River peaked at 1179 cfs; maximum turbidity 51 NTU, suspended sediment 78 mg/l. Fly Creek peaked at 226 cfs, yet maximum turbidity was only 7 NTU (see Figure A3). Samples not filtered for mg/l. Rainfall 5.75 inch.

2/4/77 to 2/8/77 Sampled at 4-hour interval. Clearwater River dropped from 122 to 81 cfs; sediment less than 1 mg/l all period. Fly Creek dropped from 5.7 to 3.8 cfs; sediment less than 1 mg/l all period. Rainfall 0.45 inch.

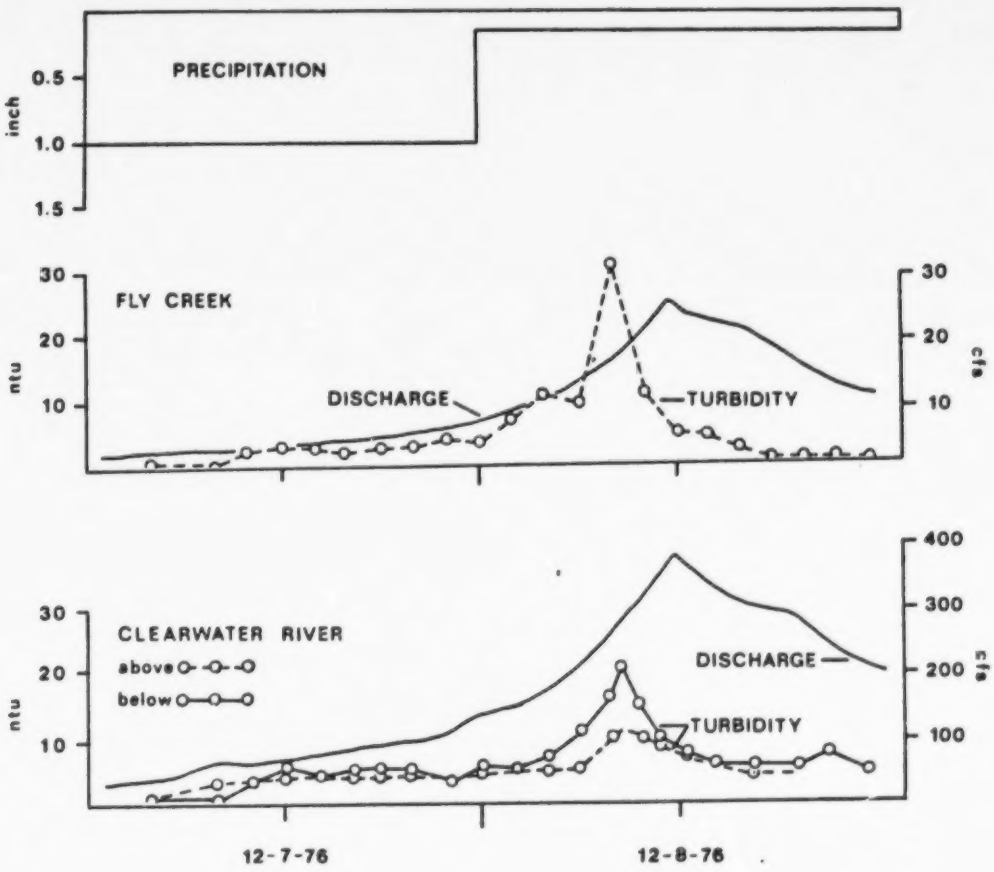

Figure A2. Early winter storm of medium intensity which occurred during the first inactive period while the road was not in use. Turbidity, rather than concentration, is presented. Fly Creek turbidity as well as resultant turbidity in the Clearwater River are shown.

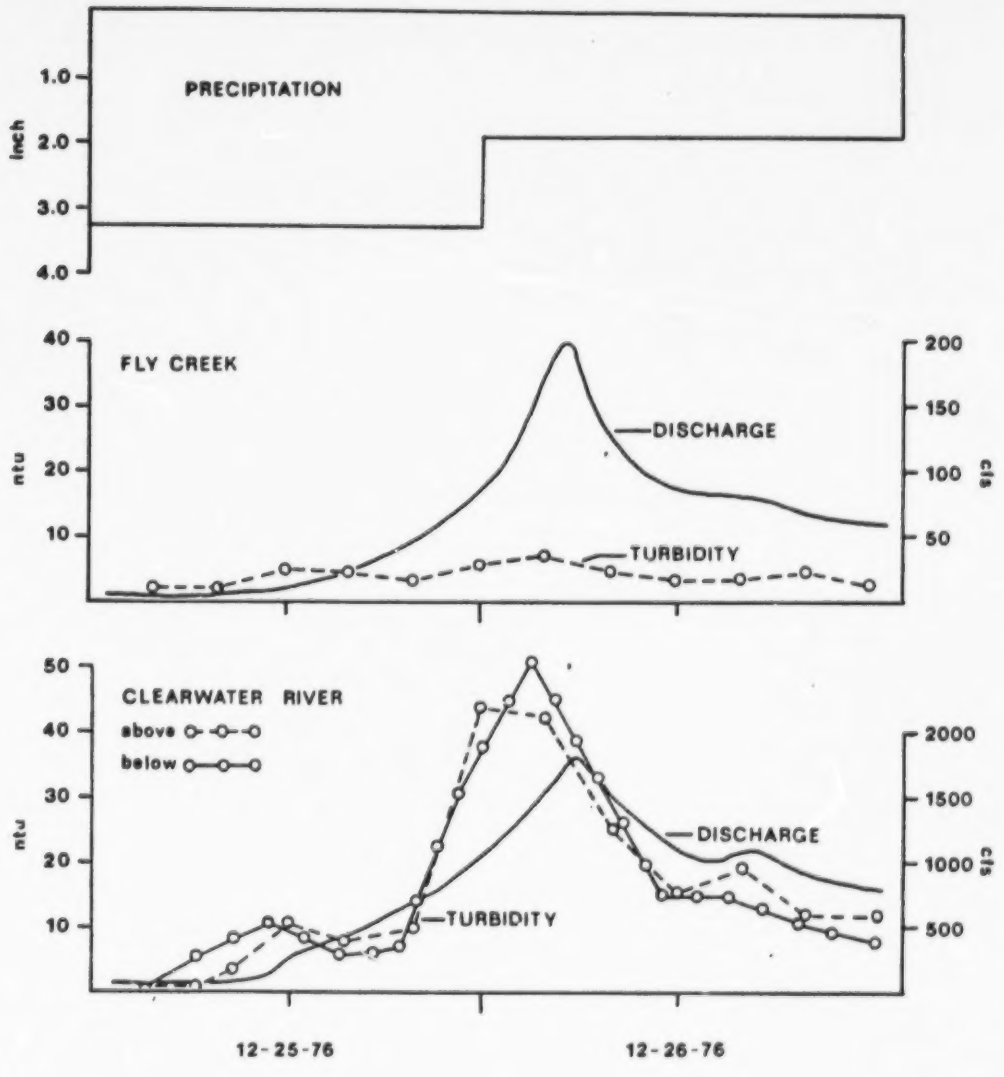

Figure A3. A major winter storm which occurred during the first inactive period while the road was not in use. Turbidity, rather than concentration, is presented. Fly Creek and Clearwater River turbidities are shown.

3/4/77 to 3/9/77 Sampled at 4-hour interval. Clearwater River peaked at 579 cfs; maximum suspended sediment concentration 62 mg/l above treatment but only 17 mg/l below treatment. Fly Creek peaked at 80.2 cfs on 3/7/77 (see Figure 13). Rainfall 8.55 inch.

Fly Creek

	Time	NTU	mg/l	cfs	in. precip.	lbs transported
3/5/77	1900	less than 1 mg/l		8.4	0	
	2300	2	11	9.6	0.35	95
3/6/77	0300	3	5	10.8	0.25	49
	0700	3	9	12.9	0.30	104
	1100	7	17	20.0	0.80	306
	1500	4	7	26.6	0.40	167
	1900	4	8	28.3	0.50	92
	2300	7	21	33.7	0.35	289
3/7/77	0300	14	31	37.9	0.50	479
	0700	8	20	50.0	0.45	899
	1100	15	42	59.6	0.70	2252
	1500	130	477	76.7	0.92	32909
	1900	18	63	66.5	0.23	3768
	2300	9	25	58.7	0.14	1320
3/8/77	0300	7	22	45.1	0.31	892
	0700	5	15	38.1	0.12	513
	1100	4	10	38.6	0.53	347
	1500	6	12	49.8	1.20	538
	1900	13	27	57.5	0.17	1396
	2300	8	23	47.8	0.03	989
3/9/77	0300	4	12	42.4	0.30	458
	0700	"end sampling"				
				Total less background		23.75 tons

3/9/77 to 3/13/77 Sampled at 4-hour interval. Clearwater River dropped from 340 to 146 cfs; little sediment carried above background. Maximum concentration 12 mg/l for one sample. Fly Creek dropped from 40 to 12 cfs; little sediment carried above background. Highest concentration was 12 mg/l for one sample. Rainfall 1.52 inch.

3/21/77 to 3/25/77 Sampled at 4-hour interval. Clearwater River increased from 87 cfs, peaked at 197 cfs, dropped to 166 cfs by end of period; sediment less than 1 mg/l all period. Fly Creek increased from 6.6 cfs to a peak of 18.2 cfs on 3/22/77, dropped to 11.8 cfs by end of period. No sediment above background transported during entire period. Rainfall 1.16 inch.

4/4/77 to 4/8/77 Sampled at 4-hour interval. Clearwater River mean discharge 140 cfs; sediment less than 1 mg/l all period. Fly Creek mean discharge 14 cfs; sediment less than 1 mg/l all period. No rain.

4/13/77 to 4/14/77 Sampled at 4-hour interval. Clearwater River mean discharge 130 cfs; sediment less than 1 mg/l all period. Fly Creek mean discharge 11 cfs; sediment less than 1 mg/l all period. Rainfall 0.48 inch.

5/3/77 to 5/7/77 Sampled at 4-hour interval. Clearwater River dropped from 206 to 100 cfs; highest concentration 10 mg/l for one sample, mostly background level. Fly Creek dropped from 19 to 7.8 cfs (see Figure A4). Rainfall 1.42 inch.

Fly Creek

	Time	NTU	mg/l	cfs	in. precip.	lbs transported
	0700	"no sample"		16.0	0.33	
	1100	5	6	15.8	0.24	85
	1500	5	21	15.5	0.05	293
	1900	6	21	14.6	0.11	276
	2300	"background"		13.7	0.07	6
5/4/77	0300	4	6	12.8	0.08	69
	0700	2	3	12.1	0.16	33
	1100	3	12	11.8	0.05	127
	1500	"background"		12.4	0.12	6
	1900	"background"		13.6	0.02	6
	2300	2	3	13.7	0.07	37
5/5/77	0300	"background"		12.6	0	6
	0700	2	3	11.8	0	32
	1100	3	1	11.3	0	10
	1500	"background"		10.9	0.07	6
	1900	2	6	11.9	0.02	64
	2300	"background"		11.1	0	6
5/6/77	0300	"background"		10.4	0	6
	700	2	3	10.1	0	27
	1100	3	9	9.8	0	79
	1500	3	12	9.5	0	103
	1900	2	3	9.2	0	25
	2300	3	6	9.0	0	49
5/7/77	0300	3	6	8.8	0	48
	0700	2	6	8.8	0.03	48
	1100	4	15	8.4	0	113
	1500	2	1	8.2	0	7
	1900	2	1	8.0	0	7
	2300	2	8	7.9	0	57
				Total less background		1485

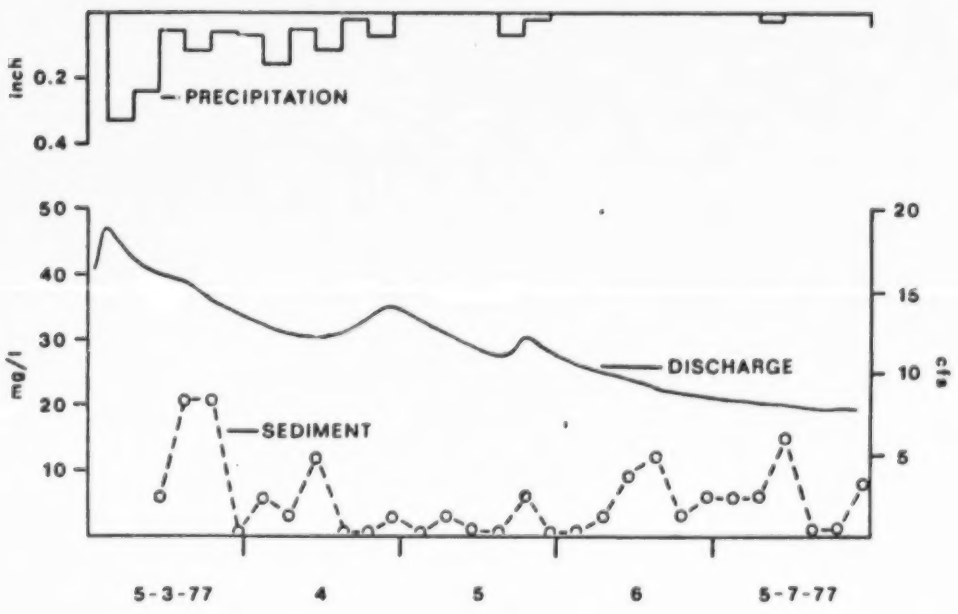

Figure A4. Fly Creek suspended sediment concentrations following a minor spring storm during the first inactive period.

5/16/77 to 5/18/77 Sampled at 4-hour interval. Clearwater River dropped from 92 to 71 cfs; sediment less than 1 mg/l all period. Fly Creek dropped from 7.1 to 5.2 cfs; sediment less than 1 mg/l all period. No rain.

5/19/77 to 5/23/77 Sampled at 4-hour interval. Clearwater River increased from 71 to 118 cfs, dropped to 72 cfs by end of period; sediment less than 1 mg/l all period. Fly Creek increased from 5.2 to 9.5 cfs on 5/21/77, dropped to 5.3 cfs by end of period; sediment less than 1 mg/l all period. Rainfall 0.65 inch.

5/24/77 to 5/28/77 Sampled at 4-hour interval. Clearwater River increased from 72 to 202 cfs, dropped to 148 cfs by end of period. Clearwater River suspended sediment concentration above treatment peaked at 45 mg/l on 5/25/77, two days before storm peak. Storm peak concentration above treatment was 7 mg/l, concentration below treatment did not exceed 7 mg/l during entire period. Fly Creek increased from 5.3 cfs to peak at 18.9 cfs on 5/27/77, dropped to 12.6 cfs by end of period (see Figure A5). Rainfall 3.57 inch, no rain on preceding two days (5/22/77 and 5/23/77).

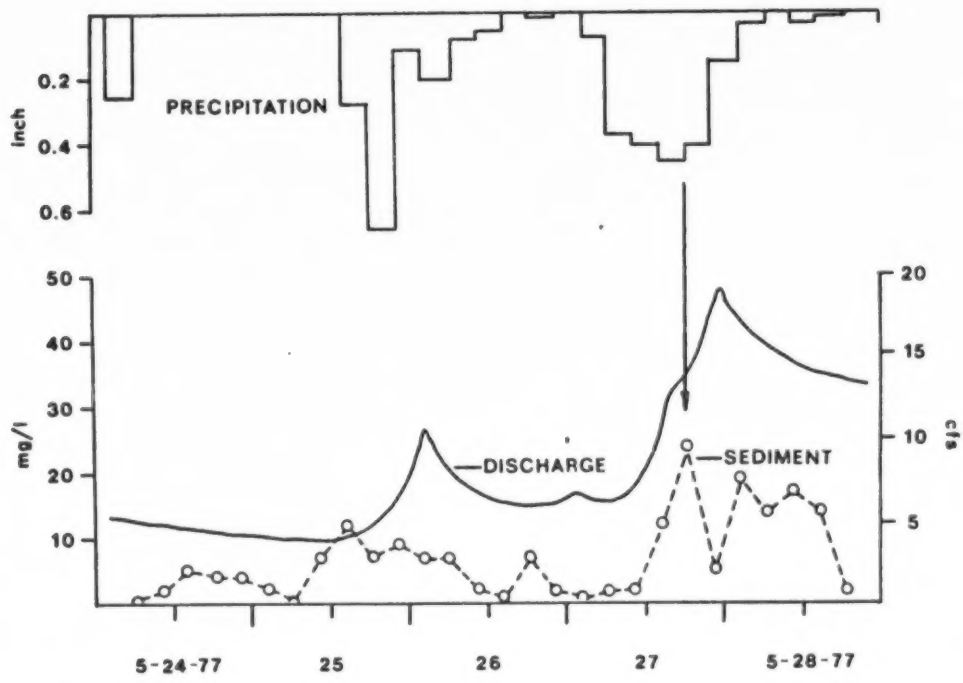

Figure A5. Fluctuations in Fly Creek suspended sediment concentrations resulting from a minor spring storm during the first inactive period.

Fly Creek

	Time	NTU	mg/l	cfs	In. precip.	lbs transported
	0630	less than 1 mg/l		5.3	0.25	
	1030	2	2	5.2	0	9
	1430	2	5	5.0	0	22
	1830	1	4	4.9	0	18
	2230	2	4	4.8	0	17
5/25/77	0230	1	2	4.7	0	8
	0630	1	0	4.6	0	0
	1030	3	7	4.6	0	29
	1430	3	12	4.5	0	49
	1830	2	7	4.8	0.28	30
	2230	2	9	5.9	0.66	48
5/26/77	0230	4	7	10.7	0.11	67
	0630	5	7	8.4	0.20	53
	1030	2	2	7.5	0.08	13
	1430	1	1	6.9	0.06	12
	1830	2	7	6.4	0	40
	2230	2	2	6.4	0.02	12
5/27/77	0230	2	2	6.8	0	12
	0630	1	1	6.5	0.07	6
	1030	2	2	6.6	0.37	12
	1430	2	2	11.0	0.40	20
	1830	3	12	13.5	0.45	145
	2230	7	24	17.5	0.40	378
5/28/77	0230	3	5	17.0	0.15	76
	0630	6	19	16.0	0.03	273
	1030	3	14	15.1	0	190
	1430	3	17	14.2	0.03	217
	1830	3	14	13.9	0.01	175
	2230	2	2	13.0	0	23
				Total less background		1840

6/2/77 to 6/7/77 Sampled at 4-hour interval. Clearwater River dropped from 148 to 86 cfs; sediment less than 1 mg/l all period. Fly Creek dropped from 12.6 to 6.5 cfs; sediment less than 1 mg/l all period. Rainfall 1.25 inch.

6/16/77 to 6/20/77 Sampled at 4-hour interval. Clearwater River dropped from 46 to 36 cfs; sediment less than 1 mg/l all period. Fly Creek dropped from 3.2 to 2.5 cfs; sediment less than 1 mg/l all period. No rain.

6/22/77 to 6/27/77 Sampled at 4-hour interval. Last sampling of winter inactivity. Clearwater River dropped from 36 to 29 cfs; sediment less than 1 mg/l all period. Fly Creek dropped from 2.5 to 2.0 cfs; sediment less than 1 mg/l all period. Rainfall 0.14 inch.

Second winter

Just prior to the second winter's inactive period, but after ROW hauling was complete, the road was resurfaced with crushed rock. Also, the Clearwater River was not monitored during the second winter.

2/3/78 to 2/5/78 Sampled at 2-hour interval. Fly Creek falling stage, dropped from 50 to 18.5 cfs. Fly Creek peaked prior to sampling, from rainfall on 2/2/78. Sediment concentrations not shown below were at background. Rainfall 1.59 inch.

Fly Creek

	Time	NTU	mg/l	cfs	in. precip.	lbs transported
	1000	"no sample"		41.0	0.08	
	1200	5	17	38.5	0.04	294
	1400	7	14	35.3	0.01	222
	1600	8	10	32.1	0	144
	1800	3	9	29.8	0	120
	2000	3	2	28.0	0	25
	2200	2	2	26.3	0	24
2/4/78	2400	2	4	25.3	0	46
	0200	3	2	24.9	0.15	22
	0400	2	1	23.1	0	10
	0600	3	4	22.3	0	40
	0800	less than 1 mg/l		21.4		
			Total less background			877

2/15/78 to 2/20/78 Sampled at 4-hour interval. Fly Creek dropped from 10.0 to 5.1 cfs; sediment less than 1 mg/l all period. Rainfall 0.47 inch.

3/6/78 to 3/8/78 Sampled at 4-hour interval. Fly Creek increased from 3.5 cfs to peak at 21.0 cfs on 3/7/78, dropped to 8.7 cfs by end of period (see Figure 14). Rainfall 3.94 inch.

Fly Creek

	Time	NTU	mg/l	cfs	in. precip.	lbs transported
	1230	less than 1 mg/l		3.6	0.28	
	1630	12	20	3.7	0.70	67
	2030	21	25	5.3	0.18	119
3/7/78	0030	5	3	6.4	0.28	17
	0430	16	22	8.2	0.80	162
	0830	37	47	12.8	0.50	541
	1230	12	10	19.0	0.27	171
	1630	8	15	20.0	0.01	270
	2030	3	7	18.5	0.15	116
3/8/78	0030	3	2	12.4	0.02	22
	0430	2	7	11.1	0.01	70
	0830	2	3	10.1	0	27
	1230	2	2	9.4	0	17
	1430	less than 1 mg/l		9.4	0	
			Total less background			1537

4/5/78 to 4/10/78 Sampled at 4-hour interval. Fly Creek dropped from 10.6 to 6.2 cfs; sediment less than 1 mg/l all period. Rainfall 0.90 inch.

4/18/78 to 4/23/78 Sampled at 4-hour interval. Fly Creek increased from 7.8 cfs to peak at 23.4 cfs on 4/21/78, dropped to 12.1 cfs by end of period; sediment less than 1 mg/l all period. Rainfall 3.11 inch.

5/5/78 to 5/9/78 Sampled at 4-hour interval. Last sample series of study. Fly Creek dropped from 3.9 to 3.4 cfs; sediment less than 1 mg/l all period. Rainfall 0.06 inch.